MANUAL FOR USERS of the UNITARY PLAN WIND TUNNEL FACILITIES of the NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

(NASA-TM-80998) MANUAL FOR USERS OF THE UNITARY PLAN WIND TUNNEL FACILITIES OF THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS (National Advisory Committee for Aeronautics) 158 p

N80-73449

Unclas

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NACA

WASHINGTON

1956

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MANUAL FOR USERS of the UNITARY PLAN WIND TUNNEL FACILITIES of the NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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INTRODUCTION

The Unitary Plan Wind Tunnels of the National Advisory Committee for Aeronautics are operated and staffed by the NACA and are available primarily to meet the needs of the aircraft industry, the military services, and other Government agencies for wind tunnel testing of large-scale models in the development of supersonic aircraft and missiles, and aircraft engines.

This Manual provides information for use in planning development testing in the NACA Unitary Plan Facilities. It includes descriptions of the three NACA Unitary Plan Wind Tunnels, information on the operating characteristics of each tunnel and preliminary information concerning model design. The procedures by which testing time may be obtained and by which the NACA operated its Unitary Plan Wind Tunnels are included. Information concerning the NACA Lewis 8- by 6-foot Supersonic Wind Tunnel is included since this facility is used in some cases in lieu of the Lewis Unitary Plan Wind Tunnel for development tests.

Caution........

The information herein concerning model design and construction is subject to change with changes in test equipment and techniques. It is recommended that model designers consult with the wind tunnel staff as early as possible in all cases. In no case is it advisable that model construction be started before this is done.

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THE "UNITARY PLAN"

Immediately following World War II the military services and the NACA made studies of the wind tunnel equipment required to establish a sound basis for the further development of aircraft and missiles. Out of these early independent studies grew a coordinated plan which was approved by the Congress in the Unitary Wind Tunnel Plan Act of 1949. The Unitary Plan as finally implemented consists of five wind tunnel installations; one at each of the three NACA Laboratories, and two, along with an Engine Test Facility, at the Air Force's Arnold Engineering Development Center at Tullahoma, Tennessee. All of the wind tunnels of the Unitary Plan were built and are operated primarily to meet the needs of industry, the military services, and other Government agencies for large Reynolds number testing of supersonic aircraft and missiles and for high-speed high-altitude testing of engines.

Seventy-five million dollars were appropriated by the Congress for the construction of the three NACA Unitary tunnels, which required four to five years to build.

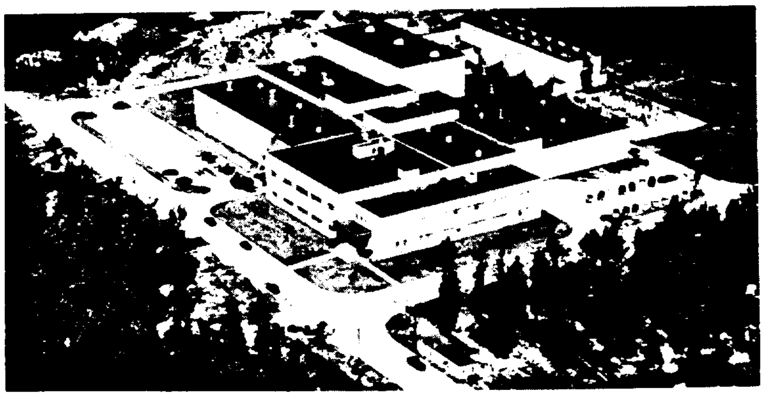
NACA's 8- by 6-foot Wind Tunnel at the Lewis Flight Propulsion Laboratory may in some cases be used in lieu of the Lewis Unitary Plan Wind Tunnel when the required Mach number is less than 2. Accordingly, information concerning the NACA Lewis 8- by 6-foot Wind Tunnel is included in this Manual.

SCHEDULES

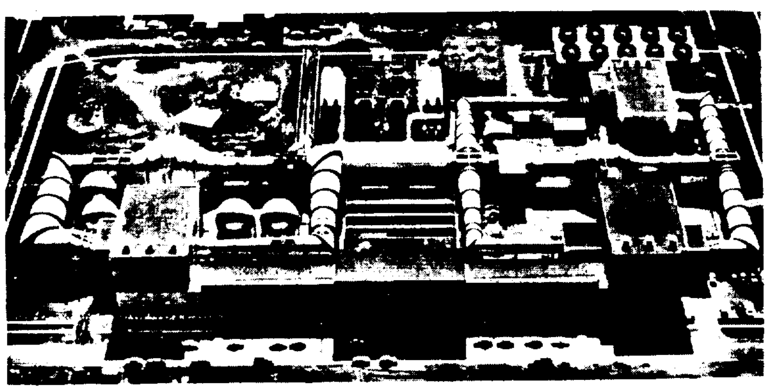
Schedules showing the allocation of testing time for Company Projects and Government Projects are established by the NACA by the twentieth day of each month for the ensuing six-month period.

GENERAL CLASSES OF WORK CONDUCTED IN THE UNITARY PLAN WIND TUNNELS

Development work in the NACA Unitary Plan Wind Tunnels is divided into two classes: Company Projects, and Government Projects. The definition of each class of project and the procedure applying to that class are presented in following sections of this Manual.



LANGLEY UNITARY PLAN
WIND TUNNEL



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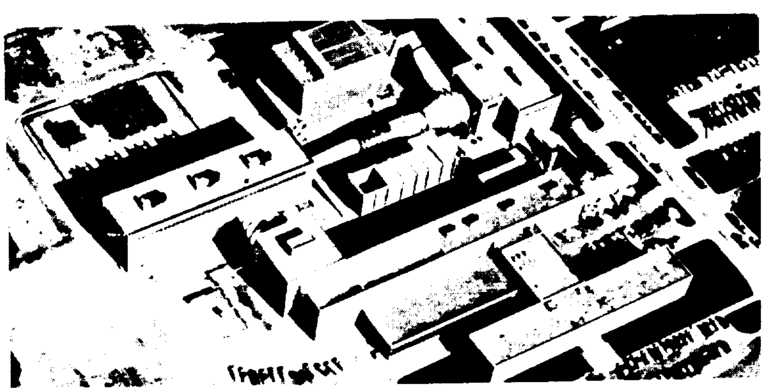
WIND TUNNEL



LEWIS UNITARY PLAN
WIND TUNNEL

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COMPANY PROJECTS

DEFINITION: Company projects consist of (1) work for industry on projects which are neither under contract with nor supported by a letter of intent from a Government agency, and (2) tests desired by a company which are related to a Government project but are beyond the scope of the tests requested by a Government agency. The fees charged for company projects are discussed later.

SCHEDULING OF TESTS: During the first year of operation of each Unitary Wind Tunnel, sixty working days are reserved for company projects. This time is divided into four approximately equal blocks not running consecutively. After this initial operating period the total reserved time and the length of each block will be adjusted to meet the future estimated workload. In scheduling the time set aside for company projects consideration will be given to the order of receipt at the NACA Headquarters of written requests for testing time as well as time previously scheduled for the company. No more than one-fourth of the annual time allocated for company projects in any facility will be assigned to a single company if there are other bona fide requests for the remaining time. For this reason, companies having several divisions operating independently should arrange for coordination within the company of requests for time in the NACA Unitary Plan Wind Tunnels for company projects.

DETERMINATION OF PROGRAM: In development testing in the Unitary Wind Tunnels, the company will be given the greatest possible freedom within the objectives of the scheduled program to obtain the precise information it requires, to determine the sequence and number of test runs to be made, and to make modifications to the program arising from the results currently being obtained, subject only to requirements of safety, practicability, and the total time assigned.

REQUESTS FOR TIME: Requests for time for company projects must be in writing, and should be addressed to: Director, National Advisory Committee for Aeronautics, 1512 H Street, N. W., Washington 25, D. C. The request should state which facility is desired for use, which test section (or sections) is desired if the tunnel involved has more than one test section, and the purpose and general range of the tests desired. The NACA Headquarters will arrange a conference with representatives of the requesting company concerning establishment of the test program, model and equipment requirements, and test schedule.

FEES FOR COMPANY PROJECTS

ELEMENTS OF FEE: The fee for a company project will consist of:

(1) A charge for occupancy of the facility;

(2) A charge for the electric power used;

(3) A charge for data reduction and the preparation of a standard data report;

(4) Special costs encountered in propulsion tests in the Lewis Unitary Plan Tunnel and the Lewis 8- by 6-foot Wind Tunnel as noted below.

OCCUPANCY TIME RATE: The occupancy charge is set by the NACA and is based on NACA cost accounting records. It does not include depreciation or amortization of the cost of the facilities. The occupancy rate will be reviewed by the NACA annually and more

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frequently as necessary to reflect major changes in costs, such as changes in wage structure. The rate existing at the time an agreement is signed by the company will apply to the project concerned. The present occupancy rates are:

Langley Unitary Plan Wind Tunnel

Precedence in use of wind tunnel drive with use of one test section	$25,000 per week
Precedence in use of wind tunnel drive with use of two test sections	$30,000 per week

Ames Unitary Plan Wind Tunnel

Precedence in use of wind tunnel drive with use of one test section	$25,000 per week
Precedence in use of wind tunnel drive with use of two test sections	$30,000 per week
Precedence in use of wind tunnel drive with use of three test sections	$35,000 per week

Lewis Unitary Plan Wind Tunnel

Aerodynamic Tests	$25,000 per week
Propulsion Tests	$30,000 per week

Lewis 8- by 6-foot Wind Tunnel

Aerodynamic Tests	$25,000 per week
Propulsion Tests (until modified to permit closed-tunnel operation)	$25,000 per week

Note: Two occupancy rates have been established for the Lewis Unitary Tunnel and the Lewis 8- by 6-foot Wind Tunnel. One occupancy rate applies to aerodynamic projects, and a different occupancy rate applies to propulsion projects. Factors which will be considered in determining which rate applies include whether fuel burning is involved in the project and whether the tunnel is operated as an open or as a closed tunnel.

The occupancy rates for propulsion projects in the Lewis Tunnels do not include (1) services and materials consumed in setting up special test rigs for engines and (2) the cost of fuel furnished by the NACA and consumed in the test engine in the course of the tests. As noted previously under ELEMENTS OF FEE when these two items occur in a project a separate charge will be made for them.

OCCUPANCY TIME: Occupancy time is defined as a period of time beginning with the scheduled date for starting the installation of the test article in the wind tunnel test section through the day on which the test article is removed from the test section and the test section is restored to its condition prior to the start of the company's test.

WORK WEEK: The normal occupancy week is a five-day week, Monday through Friday. Except as noted later in connection with operation outside the normal operating period, occupancy time will be charged in units of full days, at the rate of one-fifth of the weekly occupancy charge. No charge will be made for holidays not worked occurring during the company's period in the wind tunnel.

NORMAL OPERATING PERIOD: The large quantities of electric power required for the operation of the Unitary Plan Wind Tunnels will ordinarily permit operation only during

periods of availability of off-peak power at each NACA Laboratory. During each day of occupancy the company will have precedence in the use of the wind tunnel drive for an eight-hour period, falling within the period of availability of off-peak power. This eight-hour period is defined as the normal operating period of the facility. Approximately one hour of this time will be required for start-up and one-half hour will be required for shutdown of the tunnel. This start-up and shutdown time will vary between tunnels. For propulsion tests in the Lewis Unitary Wind Tunnel, testing time may be further reduced by limitations due to the air drying system. Within the limits of each wind tunnel and its equipment, the model, and the test program, the NACA will provide the company with the maximum testing time possible during the normal operating period.

The company is permitted access to the wind tunnel test section and its assigned shop and office facilities twenty-four hours a day on each day for which it is charged an occupancy fee. Access to the office and shop facilities is also provided for a reasonable period before and after the scheduled occupancy time.

DELAYS DURING NORMAL OPERATING PERIOD: Delays in the test schedule occurring during the normal operating period due to unavailability of power, economic considerations, breakdown or malfunction of government furnished equipment, or other reasons beyond the control of the company, will be adjusted as follows: the company will receive a credit for lost time in the occupancy time charge; or, at the option of the NACA, and with the concurrence of the company, may be allowed in lieu of a refund either an equivalent period of actual operating time outside the normal operating period or an equivalent extension of time. Delays of less than one-quarter hour will not be counted for credit purposes. Delays of one-quarter hour or more will be accumulated for credit purposes, but credit will be allowed only in multiples of one hour. The weekly occupancy charge for the facility is divided by forty to obtain the rate per hour for computing credits for delays.

OPERATION OUTSIDE NORMAL OPERATING PERIOD: The power available to the NACA during on-peak hours is almost fully utilized in operation of the NACA Laboratories. At some Unitary Wind Tunnels, power may be available at irregular times outside the normal operating period. These hours are expected to be very limited and the amount of power is expected to permit only low-powered runs. Where it is possible for the NACA to provide an operating staff for the facility outside the normal operating period, the limited amount of testing time available during other than the normal operating period in each occupancy day will be furnished to the company provided the company so desires.

CHARGE FOR OPERATING TIME OUTSIDE NORMAL OPERATING PERIOD: The company will be charged for each hour of additional testing time actually used outside the normal operating period at an hourly rate equal to one-fortieth of the weekly occupancy charge. When such additional testing time equals eight hours, the scheduled occupancy time allotted to the company will be reduced by one day.

CANCELLATION OR CURTAILMENT OF PROJECTS BY THE COMPANY: Upon determination of a test schedule by the representatives of the company and of the NACA, it will become the responsibility of the company to meet this schedule. Cancellation of a project may be made by the company without charge on sixty days' notice. In the event subsequently scheduled work cannot be conducted in lieu of the company's work, when canceled with less than sixty days' notice, the company shall be liable for the occupancy time charge for the scheduled test period or for the period the facility test section is idle due to the cancellation, whichever results in the smaller charge. Curtailment of a project under way before the end of the scheduled test period may be made by the company. In this event the company shall be liable for the occupancy charge for the balance of the time scheduled or for the idle occupancy time of the test section, whichever is the smaller.

CHARGE FOR ELECTRIC POWER: The charge for electric power will be determined from the energy consumed during the tests and the average cost of power to the NACA Laboratory at which the tunnel is located during the month or months in which such tests are run.

DATA REPORTS: The basic report for company projects will consist of plotted curves or tabulated data without detailed analysis but with adequate description of methods and techniques employed to permit proper interpretation of the data. The original test data will be held in secured files by the NACA for a period of two years, after which disposition will be determined by conference with the company. The data will not be released in any form without the concurrence of the company.

CHARGE FOR PREPARATION OF DATA REPORT: The company will be charged for data reduction and preparation of the standard data report. The charge covers labor, materials, and overhead.

AGREEMENTS: The agreement between the company and the NACA will be on NACA Contract Form No. 362, signed by a responsible official of the contracting company. This signed contract must be received at NACA Headquarters sixty days before the scheduled date for start of the tests. All agreements will be understood to involve acceptance by the company of the conditions set forth in "Regulations for Development Work for Industry in NACA Wind Tunnels and Engine Test Facilities" published in Federal Register, Vol. 19, No. 178, September 14, 1954, pp. 5947-5948, and the information in this Manual describing the manner in which the Unitary Plan Wind Tunnels are operated.

BILLING: The billing for work in NACA Facilities will be made, so far as may be possible, at the time the data report is forwarded to the company. The Director of the NACA may, however, at his discretion, require a covering deposit before work is started on a project.

RESPONSIBILITY FOR DAMAGES: The NACA will be responsible for loss of or damage to the model or apparatus of the company only if and so far as such loss or damage is attributable to gross negligence on the part of NACA personnel. The company will be responsible for loss or damage to the NACA Facility or apparatus only if and so far as such loss or damage is attributable to gross negligence on the part of any officer or representative of the company.

GOVERNMENT PROJECTS

DEFINITION: Government projects consist of work for industry on projects which are either under contract with or supported by a letter of intent from a Government agency. Development work on Government projects must be requested by the Government agency involved. No fees are charged for this type of work.

PROJECTS ALLOCATION AND PRIORITY GROUPS: For coordinating Government projects, two groups have been established jointly by the Department of Defense and the NACA. Each group consists of one representative each from the Air Force, Army, Navy, and NACA, competent to determine military priorities in the use of the NACA and other Government-owned facilities. One group is known as the Aircraft and Missiles Projects Allocation and Priority Group and the other as the Propulsion Projects Allocation and Priority Group.

INITIATION OF GOVERNMENT PROJECTS: On request from a Government agency for the NACA to undertake a given project, NACA Headquarters, if necessary, will arrange a conference between representatives of the company, the sponsoring Government agency, and the NACA staff. This conference will review the objectives and scope of the work, the required models and instrumentation, and the availability of facility time; and then if so desired by the sponsoring Government agency will recommend a test schedule consistent with those factors. Recommended test programs and schedules will be forwarded to the allocation and priority group concerned for approval of the allocation request and for assignment of appropriate priority when in conflict with the demands of other programs.

SCHEDULING OF TESTS: Government projects will be scheduled with due consideration of the priorities established by the projects allocation and priority groups.

TEST DATA REPORTS: As for company projects the basic report for Government projects will consist of plotted curves or tabulated data without detailed analysis but with adequate description of methods and techniques employed to permit the proper interpretation of the data.

For Government projects, extended analysis and general dissemination of information of a basic nature may be made with the concurrence of the sponsoring Government agency.

MODEL PREPARATIONS AND CONDUCT OF TESTS

Caution........

The information herein concerning model design and construction is subject to change with changes in test equipment and techniques. It is recommended that model designers consult with the wind tunnel staff as early as possible in all cases. In no case is it advisable that model construction be started before this is done.

INSTRUMENTATION AND MODEL DETAILS: Each facility provides standard instrumentation suitable for the test range of the respective facility and computing equipment for the reduction of test data. This Manual contains information for each facility on

the permissible size of model, standard balances, safety margins to be used in the construction of models, model mounting details, and other pertinent factors. In the case of models of aircraft and missiles, the model should be designed to contain one of the standard balances if possible and to fit the model support. If the standard instrumentation furnished by the facility does not meet the test requirements, the company will provide suitable instrumentation which will be calibrated by the facility staff to insure accuracy of measurement. Serious delays arising from inaccuracies in company supplied instrumentation, if occurring during the scheduled test period, may result in reassignment of the position of the tests on the facility schedule. Detailed specifications and arrangements for special instrumentation will be established by mutual agreement. Information concerning drawings needed, model strength requirements, and when they should be provided is contained in the detailed description of each tunnel.

CHANGES IN TEST PROGRAM: All tests will be conducted under NACA supervision. By agreement between company representatives and the laboratory staff changes in the test program within the objectives of the scheduled program may be made. Where warranted and time is available, extensions may be made in the originally scheduled test period not exceeding 15 percent.

TRANSMITTAL OF DATA: The NACA staff will be responsible for obtaining all test data, its reduction to suitable coefficient form, and its accuracy, but the NACA will assume no responsibility for the interpretation placed on the data by others. Transmittal of the data will be made as rapidly as possible. For company projects the data will be transmitted as directed by the company. The data for Government projects will be transmitted simultaneously to the sponsoring Government agency and the contractor, unless otherwise directed by the sponsoring agency.

PRIVACY FOR PROPRIETARY WORK: During the conduct of development testing the NACA will furnish private shops and office space to companies whose projects are under test. Proprietary information will be held in confidence by the NACA.

CORRESPONDENCE AND SHIPPING

Correspondence relating to the following should be addressed to: Director, NACA Headquarters, 1512 H Street, N. W., Washington 25, D. C.

(a) Requests for copies of this Manual.
(b) Requests for test schedules.
(c) Requests for testing time for company projects.
(d) Requests for information concerning costs.

After initial arrangements have been made, correspondence relating to visits to the NACA Laboratories to discuss projects to be conducted in the NACA Unitary Plan Wind Tunnels should be addressed to the Director of the Laboratory concerned.

Correspondence relating to the following should be addressed to the Director of the Laboratory involved, at the address shown in the section of this Manual describing the Wind Tunnel:

(a) Requests for drawings of balances and other equipment.
(b) Requests for technical information concerning any phase of the tests or results.
(c) Requests for jigs or gages required to assure proper mating of parts furnished by contractor with tunnel equipment.
(d) Requests for information concerning the Wind Tunnel not contained herein.

Models, balances and other equipment should be shipped to the Laboratory involved, to the shipping address included in the information concerning each tunnel. All equipment must be packed and shipped in substantially constructed containers with readily removable tops.

THE LANGLEY UNITARY PLAN WIND TUNNEL

Langley Aeronautical Laboratory
Langley Field, Virginia

NACA

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THE LANGLEY UNITARY PLAN WIND TUNNEL

GENERAL DESCRIPTION

The basic elements of the Langley Unitary Plan Wind Tunnel are a 100,000-horsepower compressor drive system, a dry air supply and evacuating system, a cooling system, and the necessary interconnecting ducting to produce the proper air flow through either of two test sections. The locations of the basic elements of the Langley Unitary Plan Wind Tunnel are shown schematically in figure 1.

The low range test section (number 1) has a design Mach number range of from 1.5 to 2.9. The stagnation pressure can be varied up to a maximum of approximately 60 psia. The high range test section (number 2) has a design Mach number range of from 2.3 to 5.0. Its maximum stagnation pressure is approximately 150 psia.

The drive system consists of a 20,000-horsepower liquid-rheostat-controlled wound-rotor starting motor driving through a gear box to the main drive line-up. This line-up consists of a 63,333-horsepower synchronous motor driving six large capacity centrifugal compressors. The combined maximum overload capacity of the two motors is 100,000 horsepower for thirty minutes. The compressors can be arranged in five different configurations by valves in the interconnecting ducting in order to provide the wide range of volume flows and compression ratios required for the two test sections. Since the capacity of the drive system will supply only one of the test sections at a time, they cannot be operated simultaneously. The system that supplies air to the tunnel consists of compressors, vacuum pumps, and air dryer and air storage vessels as shown in figure 1. It supplies air to the tunnel at a dewpoint of lower than -65° and at the required stagnation pressure, and provides for evacuation and recharging of the tunnel or portions thereof for purging and starting.

TEST SECTIONS

Both test sections are of the asymmetric sliding-block, closed-working section type; the working section (region in which model is mounted) is 4 feet high, 4 feet wide, and approximately 7 feet long. Each test section will permit variation of Mach number at any desired increment throughout its range with the tunnel operating. Both stagnation pressure and stagnation temperature may be controlled independently.

Figure 2 shows the tunnel outline in the region of the test section. The relative location of the schlieren windows with respect to the test section is also shown in this figure. It will be noted that the window has a field of 59 inches by 48 inches. It is rectangular and made up of nine strips of optical plate glass, each $5\frac{1}{2}$ inches wide and separated from each other by $1\frac{1}{4}$ inches of supporting structure. This arrangement permits the attainment of a large field of view while retaining excellent optical qualities.

Electric power is available at 110 and 440 volts alternating current and 12 and 24 volts direct current. Other power supplies, either alternating current or direct current, can be furnished only by special arrangement.

MODEL SUPPORTS AND STINGS

MODEL SUPPORTS: The basic sting-type support system used in the tunnel (figure 2) is supported by a horizontal support strut extending from wall to wall in the balance section of the tunnel. The sting support may be traversed across the tunnel and the angle of the

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sting support with respect to the longitudinal axis of the tunnel may be varied. The center of rotation of the sting support is located in the test section and may be adjusted over a limited longitudinal range. Means have been provided for traversing the entire support system along the longitudinal axis of the tunnel for a distance of $40\frac{1}{2}$ inches. The angle range of the sting support is $\pm 20^{\circ}$. Several couplings which can be used to offset the angle of attack and yaw ranges are available. An adjustable angle coupling is shown in figure 3 and a rotary coupling is shown in figure 4. An alternate sting support system which uses an offset adapter is also available (figure 5).

The design loads of the support system and components are tabulated below:

Load component	Basic sting support	Couplings	[2]Alternate sting support
Normal force	7,400 lb	2,500 lb	1,100 lb
Axial force	3,700 lb	600 lb	5,500 lb
Side force	3,700 lb	2,500 lb	1,100 lb
Pitching moment	[1]264,000 in-lb	[1]75,500 in-lb	45,000 in-lb
Rolling moment	21,300 in-lb	3,000 in-lb	30,000 in-lb
Yawing moment	[1]137,400 in-lb	[1]75,000 in-lb	43,000 in-lb

[1]At upstream end of component. [2]At design center of the system.

The basic support system including the adjustable angle and rotary couplings is provided with two hundred and forty pressure tubes and ninety-six electrical leads. In addition, there are seventy-two pressure tubes in an external manifold mounted on top of the basic sting support. Pressure tubes in the basic sting support are 0.050-inch I.D., in the adjustable angle coupling 0.040-inch I.D., and in the rotary coupling 0.035-inch I.D. Pressure and electrical leads extend from a manifold outside the tunnel through the support to a manifold at the end of the sting. The pressure and electrical leads in both couplings are joined to the basic sting support by manifolds.

STINGS: The model is mounted on an internal strain-gage balance which is attached to a sting which, in turn, is attached to either the basic sting support (see figure 2) or to the alternate sting support (see figure 5). The balance will in general be provided by NACA and will be selected on the basis of load limits and availability. The sting shall be furnished as a part of the model equipment. The NACA will furnish on loan both drawings of the balance and a gage for the sting to ensure proper mating of the sting and balance. The sting just aft of the body shall contain a straight section of length equal to 2 to 2.5 times the maximum diameter of the body. The external diameter of the sting in this region shall be not greater than 0.7 of the base diameter nor 0.4 of the maximum diameter of the body (see figure 6). The sting shall then fair smoothly to the coupling on the end of the sting support with an included angle of not more than 20°. A drawing of the sting end to mate with the basic sting support is shown in figure 7. A drawing of the model sting utilized with the alternate sting support is shown in figure 8. Model stings should be designed with a load factor of four based on the yield strength of the material used for its construction. For the basic sting supports the manifolds (see figure 7) for making the pressure and electrical connections at the point where the model sting couples to the basic sting support will be furnished by NACA. Necessary gages and jigs for establishing the fit of both ends of the sting will be furnished on loan by the NACA.

In some cases, the aft end of the fuselage may not have sufficient width to permit the use of a sting of circular cross section which will have sufficient strength to carry the loads. In such cases the cross section of the sting where it leaves the body may be made to conform to the cross section of the fuselage at that point. It may also be necessary to

modify the body contour at its aft end in order to obtain sufficient section modulus for the sting. In either event, arrangements must be made in advance with the staff of the Langley Unitary Plan Wind Tunnel.

For pressure tests, either of two sting designs can be used. In one design, the sting is an integral part of the aft end of the body with a straight cylindrical portion of the sting extending to between 2 and 2.5 maximum diameters aft of the original body and then fairing to the sting support. This type of sting is shown in figure 9. Another design is similar to that used for the force-test model. With this design, a dummy balance would be used for model support.

MODEL INFORMATION

DELIVERY: The model shall be delivered to the Langley Unitary Plan Wind Tunnel at least four weeks prior to the scheduled starting date of the tests.

MODEL SIZES: The actual dimensions of models to be used depend upon so many factors that each case must be considered separately. The recommended maximum dimensions of a model for each of the test sections are listed in the following table:

	Low Mach number test section	High Mach number test section
Body diameter	7 inches	12 inches
Body length	30 inches	60 inches
Wing span	20 inches	34 inches

The model dimensions are the maximum dimensions that will permit testing at a Mach number of 1.5 in the low Mach number test section and 2.3 in the high Mach number test section over an angle-of-attack range from -2° to 20° and over an angle-of-sideslip range from -4° to 15°. The use of larger models will reduce the allowable range of test angles.

Preliminary estimates of the angular range for a model at other than the above Mach numbers can be made using test section dimensions and conventional theoretical calculating methods for determining the reflected wave length.

MODEL STRENGTH: A stress analysis of the model (and balance and sting if supplied by the user) based upon the maximum loads anticipated in the tests shall be submitted to Langley Unitary Plan Wind Tunnel no less than four weeks prior to the scheduled starting date of the test.

The model shall be designed with a safety factor of four based on the yield strength of the material to be used.

The starting loads shall be assumed to be twice the maximum loads resulting from the maximum starting steady-state dynamic pressures. The maximum starting steady-state dynamic pressures correspond to a stagnation pressure of 5 psia and are 309 psi in the low Mach number test section and 184 psi in the high Mach number test section.

FUSELAGE SPECIFICATIONS: The fuselage shall be constructed of stainless steel, dural, or suitable plastic to withstand contemplated loads, pressures, and temperatures, yet be as light as feasible. The tolerances for fuselage construction are ± 0.005 inch. The clearance between the fuselage and the sting will depend on the deflection characteristic of the balance. In most cases, a clearance of 1/4 inch will be satisfactory. If possible, provision shall be made to electrically indicate fouling between the sting and the model.

It is possible that the fuselage, especially in the case of multiengined models, boat tails to a point or a wedge at the aft end. In order to provide for a sting in such cases, the fuselage may be distorted out of true contour. The region of such distortion shall be kept to a minimum.

The fuselage shall be designed with hatches or removable sections to provide ease of installation of, and ready access to, the balance.

WING AND TAIL SPECIFICATIONS: Wing and tail surfaces shall be made of heat-treated steel, to minimize aeroelastic effects, and polished. The construction tolerances shall not exceed ±0.003 inch. Tail surfaces shall be made easily removable. Means of adjusting the angular position of the horizontal tail shall be provided.

CONTROL SURFACE SPECIFICATIONS: In order to make the most effective use of tunnel testing periods, those surfaces which are to be deflected during the tests shall be provided, wherever possible, with remote actuation and position indication.

Where hinge moments are to be measured, the control surfaces shall be provided with hinges having a minimum of friction, and with strain gages for measuring the hinge moments.

PRESSURE ORIFICE SPECIFICATIONS: All pressure orifices shall be flush and perpendicular with the external surfaces. For the low Mach number test section, the orifices shall not be less than 0.035-inch I.D. For models to be tested in the high Mach number test section, the orifices shall not be less than 0.050-inch I.D.

SPECIAL CONSIDERATIONS FOR MODELS FOR INLET INVESTIGATION: Models designed for inlet investigations shall, in general, be constructed as described above. The model body shall duplicate the full-scale configuration for sufficient distance to assure inlet and boundary-layer flows corresponding to the full-scale configuration. All canard surfaces and other appurtenances to the forebody shall be included. Ducts through the fuselage or nacelles shall be simulated to the extent that air can flow through them with the design mass-flow ratio. Mass flow shall be controlled by choking a nozzle in the model. In scaling down the model any boundary-layer bleeds shall be modified to correct for the difference in Reynolds number. Provision shall be made for the installation of dynamic pressure pickups on the model at locations such that indication of incipient flow instability (buzz) can be obtained. The dynamic pickups will be furnished by the NACA. Rakes shall be located in the model to determine pressure recovery and pressure losses at the duct exit. Mass-flow ratio will be measured by a flowmeter which contains a measuring orifice and a remotely adjustable valve to vary the flow. This flowmeter will be furnished by NACA. Rakes shall have tubes of at least 0.035-inch I.D. and the tubes shall be rigidly supported. All soldering on the rakes shall be silver soldering and the tubes shall be made of stainless steel. Rakes should be made so that tubes measure equal areas of the duct in order to facilitate pressure integration.

MISCELLANEOUS: All removable parts shall have a minimum of small wood or metal screws, and shall be doweled for accurate replacement.

All pressure tubes and electrical leads from the model shall be readily accessible to facilitate installation and maintenance in the tunnel.

All screw heads on the surface of the model shall be filled with materials which will withstand the temperatures at which the tests will be conducted. Hard wax will be satisfactory for temperatures under 150° F. Duratite, phenoline, or similar materials should be used at higher temperatures.

INSTRUMENTATION AND DATA PROCESSING

BALANCES: Strain-gage balances used in the Langley Unitary Plan Wind Tunnel will generally be sting-supported. The selection of a balance will be made at the time of the initial conference preparatory to the tests. Normally the balance will be furnished by the

Langley Unitary Plan Wind Tunnel. Drawings of typical balances are shown in figures 10(a) and (b). These balances will satisfy the requirements of most airplane and missile configurations. Other balances with maximum normal forces up to 2000 pounds and different distributions of force and moment ranges can be made available in most cases if necessary. Considerable time can be saved if a dummy aft end of the model is furnished the Langley Unitary Plan Wind Tunnel before the model is completed in order that a fouling check of the balance and sting may be made to ensure proper clearances within the model for all contemplated loads. The pitch center of the balance should be placed as closely as possible to the center-of-gravity location for the full-scale aircraft.

In the event that the user furnishes the balance and if the balance is known to be in acceptable mechanical and electrical condition, if it has been used previously at another facility, and if a calibration is available, the balance together with the supplementary equipment shall be made available to the Langley Unitary Plan Wind Tunnel a minimum of four weeks prior to the start of the scheduled test period. If the balance has not been used before or is not known to be in perfect condition, it shall be made available to the Langley Unitary Plan Wind Tunnel at least six weeks prior to the scheduled test date. If circumstances permit, this period should be increased to allow for unforeseen difficulties in the calibration.

All calibration fixtures and supplementary equipment necessary for a complete calibration of the balance in the model and a determination of the alinement of the model and the balance will be furnished by the user. The user will also furnish all calibration fixtures and equipment for calibration and positioning of all control surfaces and all surfaces to be investigated.

All holes in the model for balance attachment, whether the balance is furnished by the Langley Unitary Plan Wind Tunnel or by the user, shall be drilled at the laboratory.

PRESSURE MEASUREMENTS: Pressure measurements will generally be made with manometers; their locations at the test sections are illustrated in figure 1. The standard-manometer units have twenty-five tubes and are 10 feet high. These manometers may be filled with any of the common manometer fluids to permit reading a wide range of pressures with a high degree of accuracy. Manometer records are obtained by photography. The films are read and the data are punched into IBM cards by means of telecordex units.

When necessary, various special types of equipment will be available. These include sixteen channels of carrier equipment, recording oscillograph and pickups for making dynamic measurements, a pressure integrator, and mechanical optical pressure recorders for pressures outside the range of the manometers.

SCHLIEREN EQUIPMENT: Each test section is provided with a schlieren system having a 49-inch diameter field. The complete system is supported from a beam which rides on rails and may be translated as a unit along the longitudinal axis of the tunnel to provide complete coverage of the 59-inch schlieren window. The schlieren photographs are taken with an automatic 9-inch by 9-inch aerial camera.

A portable 12-inch diameter system will also be available and can be set up for a more detailed examination of any particular test area.

DATA PROCESSING: A semi-automatic force data readout system, located as shown in figure 1, provides tabulated raw data and IBM punch card storage of raw data concurrent with the operation of the wind tunnel. Each test section is equipped to handle twelve channels of wire strain gage or other bridge type data output. When necessary, the equipment for the two test sections can be interconnected so that a maximum of twenty-four channels can be obtained.

The wire strain-gage indicators of the readout system are self-contained electronic indicators designed for use with a full bridge wire strain gage. A shaft position analog-to-digital converter is a part of each unit. Normal operating repeatability over a period of days, assuming constant input, is within ±0.1 percent of full scale. Linearity is within 0.1 percent of full scale.

Normally, about 7.5 volts filtered direct current is supplied to 120-ohm gages. With this type of operation, 1000-microinch strain will give a 2000-count span. If the gage factor is two, the 2000-count span will be equivalent to approximately 15 millivolts output of the gage. If the value of supply voltage given above produces too much strain-gage heating, a reduced gage voltage can be used. It should be noted that a reduction of supply or output voltage will result in a reduced indicator span. Thus with a repeatability of ±2 counts, the percentage accuracy of the indication will decrease as the span is decreased.

FACILITIES PROVIDED TO USERS

For security reasons and in order to provide the compartmentation necessary for the protection of his proprietary interests, each user will be assigned to a private shop for his exclusive use from the time the model is received until the completion of the test period; the locations of the shops are shown in figure 1. This shop, which is about 24 by 46 feet in size, will be equipped with the following:

- Monorail with 1/2-ton hoist
- Work benches and vises
- Surface plate, 18 inches by 30 inches
- Pedestal grinder
- 1/2-inch floor model drill press

A portable cabinet containing a variety of hand tools can be issued to each user if requested. This cabinet shall be turned back to the tool crib attendant on completion of the tests.

Larger power tools, welding, and soldering equipment will be located in the general shop of the facility and will be available for use by all users.

A model dolly will be provided upon which the model can be assembled, check balance calibrations made, sting fouling checked, and the model transported to the test section.

Private office space can be made available to each user for the duration of the tests if required; the locations of the users' offices are shown in figure 1.

OPERATING CHARACTERISTICS AND POWER COST ESTIMATING

OPERATING CHARACTERISTICS: The predicted maximum stagnation and dynamic pressures plotted against Mach number are shown in figures 11 and 12, respectively. The corresponding maximum Reynolds number per foot of model length plotted against Mach number is shown in figure 13. The evacuation equipment will reduce the stagnation pressure to approximately $1\frac{1}{2}$ psia. This does not mean, however, that the tunnel will operate satisfactorily aerodynamically at such low pressure at the upper end of the Mach number range. Information on the lower practical limit of stagnation pressure will be determined during the calibration. For preliminary purposes, this limit should be taken as approximately one-tenth of the maximum.

POWER COST ESTIMATES: In estimating the time required for a given series of tests, it may be assumed that data can be taken at the rate of approximately one minute per data point for force tests and five minutes per data point for pressure tests. Shutdown for configuration changes will require approximately two hours from the last data point of one run to the first data point of the next run plus whatever time is required for making the model configuration change. A start-up time of one hour at the beginning of the operating shift is required before data can be taken and a shutdown time of approximately one-half hour must be allowed at the end of the operating shift.

In estimating energy costs, a rate of $1\frac{1}{2}$ cents per kilowatt hour may be used. The power required at a given Mach number and stagnation pressure can be determined from figure 14.

INFORMATION TO BE SUPPLIED BY THE USER

The user shall furnish the following information as soon as possible after the tests have been requested:

I. Model Details and Stress Analysis

A. DRAWINGS OF MODEL

1. Three-view suitable for inclusion in a report
2. One complete set of drawings or sketches providing the following data pertinent to the model:
    a. All configurations to be tested; configurations shall also be listed in tabular form and cross-referenced to drawings
    b. Weight and center-of-gravity location for all configurations
    c. Materials employed in fabrication with their physical properties
    d. Heat treatments
    e. Types of bolts, screws, and other fasteners
    f. Weld dimensions
    g. Special methods of adhesive bonding
    h. Location of suitable reference stations for orientation of model in tunnel, including description of means for determining angular relationships
    i. Location and identification of pressure rakes, probes, and orifices

B. DRAWINGS OR SKETCHES OF MODEL INSTALLATION: These drawings or sketches shall show the relation between the model, the balance, the sting, and the sting support. The model reference stations identified under the preceding section entitled DRAWINGS OF MODEL shall be used in locating the model with respect to the support system. The leading edge of the traversing support strut shall be taken as the basic reference line for the model support system. References to all detail drawings and subassemblies should be clearly shown.

C. TABULATED DATA: The detailed information listed in table I of this Manual shall be submitted. (Table I is found following this text.)

D. TEMPLATES: The company shall provide templates of all critical surface contours (such as body and duct contours, airfoil sections, etc.). A surface shall be considered critical if deviations from the prescribed ordinates would influence the test results. The number of templates to be provided is not specified, but should be sufficient to establish the conformation of the surface with the desired ordinates.

E. STRESS ANALYSIS: A stress analysis of the model (and balance and sting if supplied by the user) based upon the maximum loads anticipated in the tests and on the information supplied in the preceding section on MODEL STRENGTH shall be submitted to the Langley Unitary Plan Wind Tunnel nc less than four weeks prior to the scheduled starting date of the tests.
Each section devoted to a detailed analysis shall contain a sketch showing the design forces and moments acting, the general equations for the stress distribution and a concise statement of the assumptions and approximations involved. Section properties of structural members (both bending and torsion) shall be shown at an adequate number of stations to facilitate a check on the location of the designated critical sections.

F. REVISIONS: The Langley Unitary Plan Wind Tunnel should be notified immediately of any changes to the model, balance, or model support system which involve the structural integrity of the installation, the test procedure

or results, or the instrumentation. Reasons for the revisions should be stated. If the structural integrity is involved, additional stress analysis should be submitted to show satisfactory safety has been maintained.

II. Test Program

A. ITEMS: The proposed test program should include the following items:

1. A statement of the purpose of the tests and a summation of the objectives of the proposed test program.
2. List of the data desired: e.g., six-component force data, duct-inlet pressure recoveries, mass-flow measurements, control surface hinge moments, pressure-distribution data, etc.
3. Tentative schedule of the tests indicating model configuration (cross-referenced to the table of model configurations), tunnel operating conditions, increments and ranges of the variable parameters, and the data to be taken at each condition.
4. A schedule of tests on which schlieren observation is required (cross-referenced to table of model configurations).

III. Data Analysis Information

A. MODEL AREAS AND DIMENSIONS: All areas and model dimensions required for computation factors. Tabular form preferred.

B. AXIS SYSTEM: Axis system about which final coefficients are to be presented.

C. PLOTTED RESULTS: Desired form of plotted results.

D. COEFFICIENTS AND LOADS: Required force and moment coefficient accuracies and estimated model loads.

E. PRESSURE MEASUREMENT: Required pressure measurement accuracies and estimated extreme values relative to test section dynamic pressure.

F. INTERNAL FLOW: The design direct-inlet pressure recoveries and design mass-flow ratios for the test conditions.

G. USER'S BALANCES: For user-furnished balances, all calibration factors and calculative procedures necessary for data reduction.

H. SPECIAL DATA: Schedule of any special data required such as balance calibration, including regions of load centers expected in tests, probe calibrations, etc.

I. SUPPLEMENTARY TEST RESULTS: Test results from other facilities that would aid in data analysis, such as reports, figures, etc.

SHIPPING ADDRESS

Material shipped to the Langley Unitary Plan Wind Tunnel to be incorporated as a part of the model or test should be addressed as follows:

Langley Unitary Plan Wind Tunnel
NACA Langley Aeronautical Laboratory
Langley Field, Virginia

A return address and some type of model identification must be attached to the outside of the container.

TABLE I

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

LANGLEY UNITARY PLAN WIND TUNNEL MODEL DATA

Date forwarded ____________________

Model designation ____________________ Model scale ____________________

C.g. location	Longitudinal, ft from L.E. M.A.C.	
	Vertical, ft (above, below) fuselage reference	

Ⓐ Main surfaces

ITEM		Surface: Wing (Total / Exposed)	Horizontal tail (Total / Exposed)	Vertical tail (Total / Exposed)	Canard (Total / Exposed)	Tip control	②
Type							
Area, sq ft							
Span, ft							
M.A.C.	Length, ft						
	Longitudinal location, ft						
	Vertical location, ft						
	Lateral location, ft						
Aspect ratio							
Tip chord length, ft							
Root chord length, ft							
Root chord location	Longitudinal, ft						
	Vertical, ft						
Taper ratio							
Airfoil section ①	Root						
	Tip						
Leading-edge radius							
Sweepback of quarter-chord line, deg							
Dihedral angle, deg							
Incidence angle, deg							
Geometric twist, deg							
Loading, lb/ft^2							
Tail length							

Ⓑ Control surfaces

ITEM			Surface: Elevator	Aileron	Nose flap	Trailing-edge flap	Rudder	Speed brakes and spoilers	③
Type									
Area, sq ft									
Span, ft									
Location of ④	Longitudinal hinge ℄, ft								
	Lateral	Inboard edge, ft							
		Outboard edge, ft							
	Chord	Inboard edge, ft							
		Outboard edge, ft							
Sweepback of hinge ℄, deg									
Distance from hinge ℄ to centroid of area, ft									
Type and amount of aerodynamic balance									
Deflection range, deg or height/chord									
Airfoil section									
Trailing-edge thickness ratio									

Ⓒ Fuselage

Length, ft		
Width, ft		
Depth, ft		
Frontal area, sq ft		
Fineness ratio	Overall	
	Forebody	
	Afterbody	
Side area, sq ft		

Volume, cu ft		
Base area, sq ft		
Cavity area, sq ft		
Effective nose cone angle deg		
Duct areas	Inlet, sq ft	
	Comp. face, sq ft	
	Exit, sq ft	
Mass-flow ratio	Model	
	Prototype	

Ⓓ External stores

Length, ft		
Frontal area, sq ft		
Fineness ratio		
C.g. location from store nose	Longitudinal, ft	
	Vertical, ft	
Incidence, deg		

Notes:
① Give orientation
② Other types of all-movable surfaces
③ Slots, slats, etc.
④ For rudder inboard equals lower, etc.
⑤ Balance center to be as close as possible to prototype c.g.

Ⓔ Tunnel balance

Pitch beam center ⑤		
Location	Longitudinal, ft	
	Lateral, ft	
	Vertical, ft	
	Percent, M.A.C.	
Yaw beam center		
Location	Longitudinal, ft	
	Lateral, ft	
	Vertical, ft	
	Percent, M.A.C.	

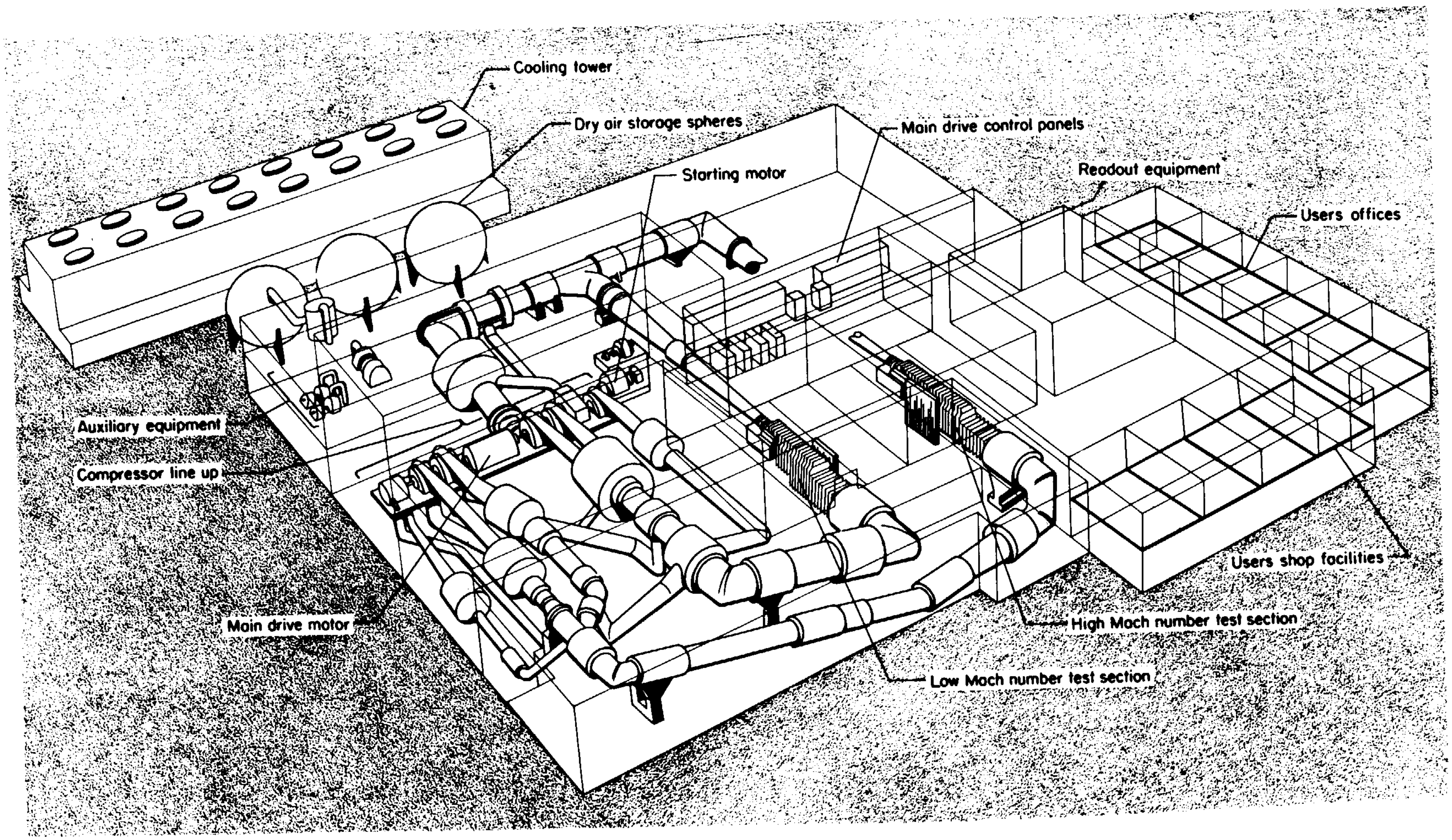


Figure 1. - Schematic drawing of Langley Unitary Plan Wind Tunnel.

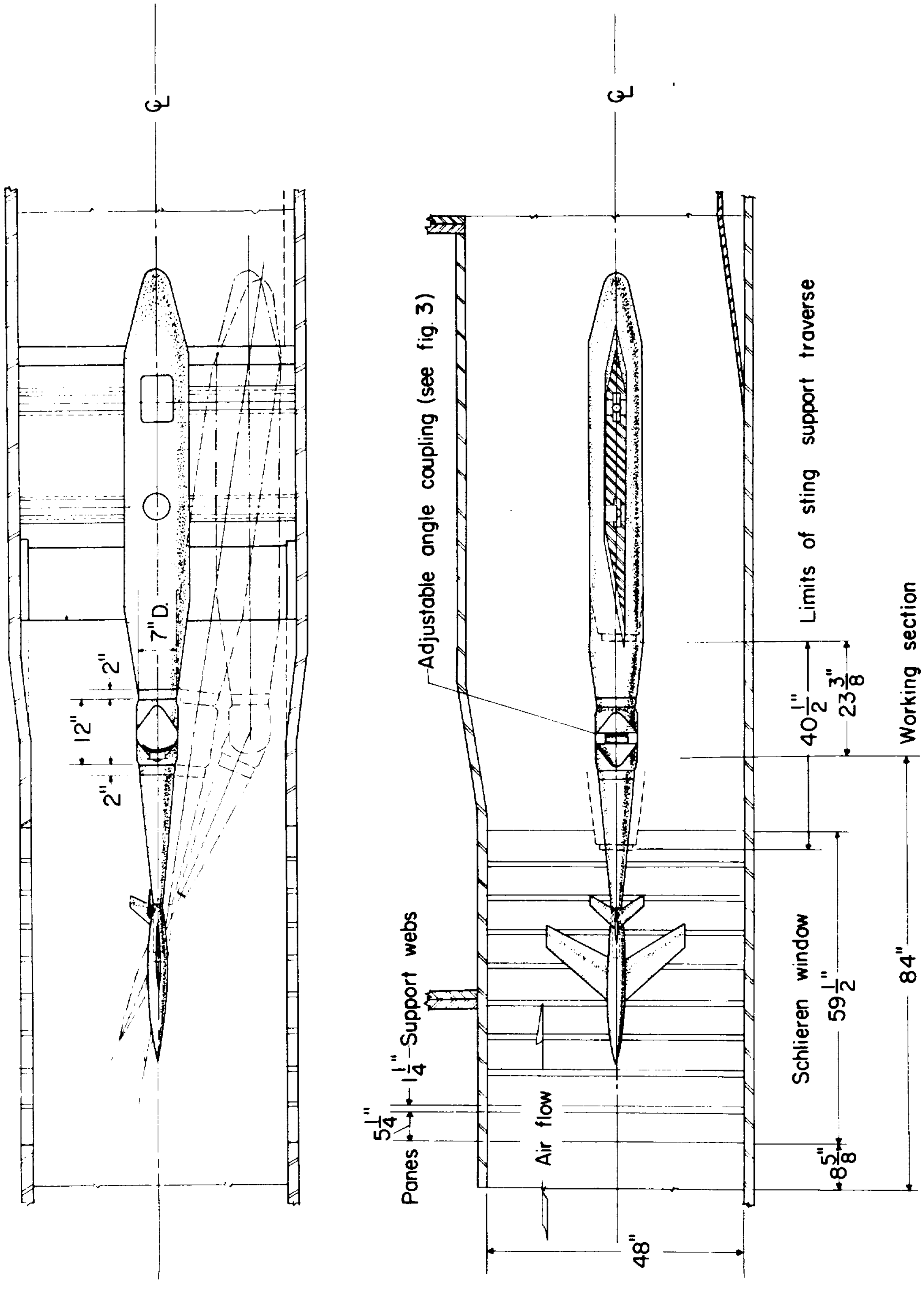


Figure 2. - Test section and basic sting support system, Langley Unitary Plan Wind Tunnel.

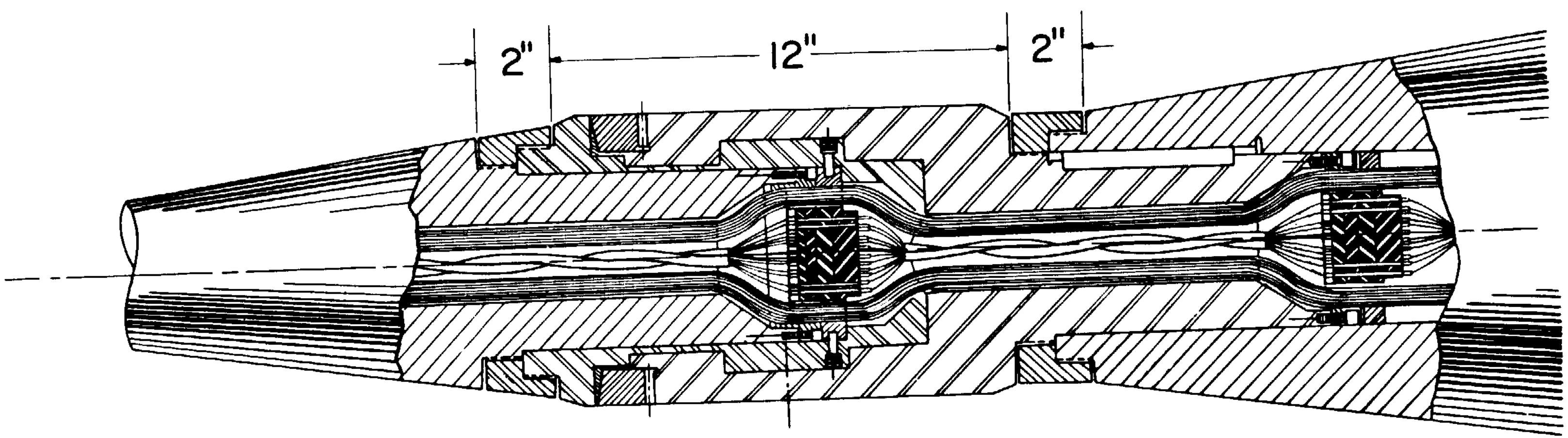


Figure 3. - Adjustable angle coupling, Langley Unitary Plan Wind Tunnel.

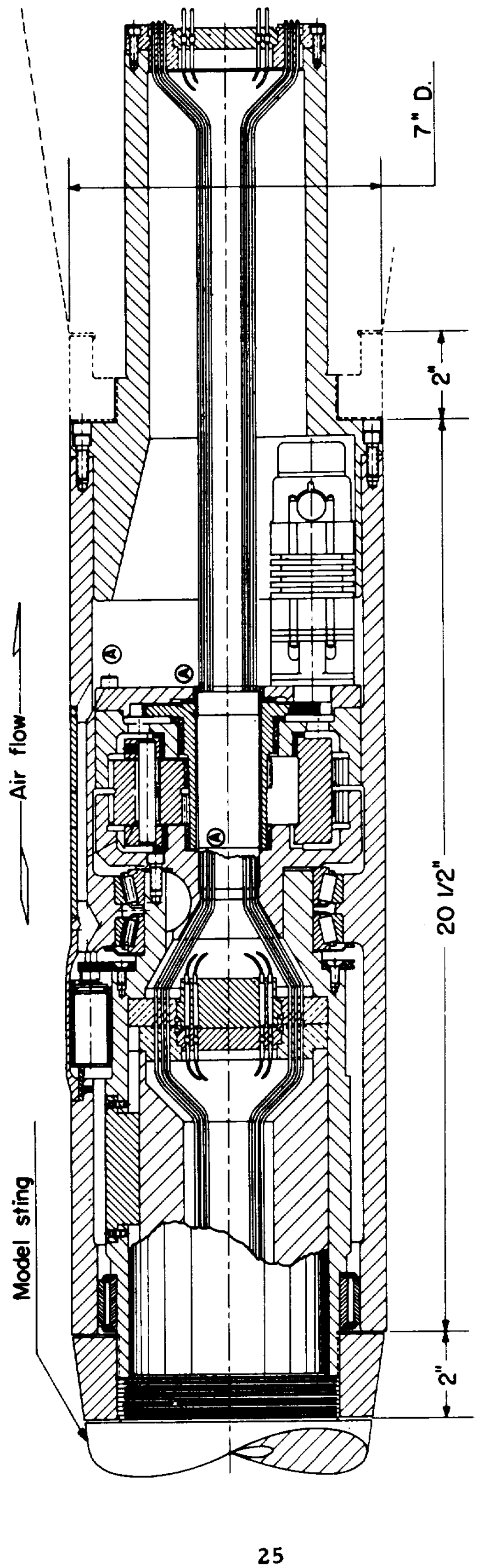


Figure 4. - Rotary coupling, Langley Unitary Plan Wind Tunnel.

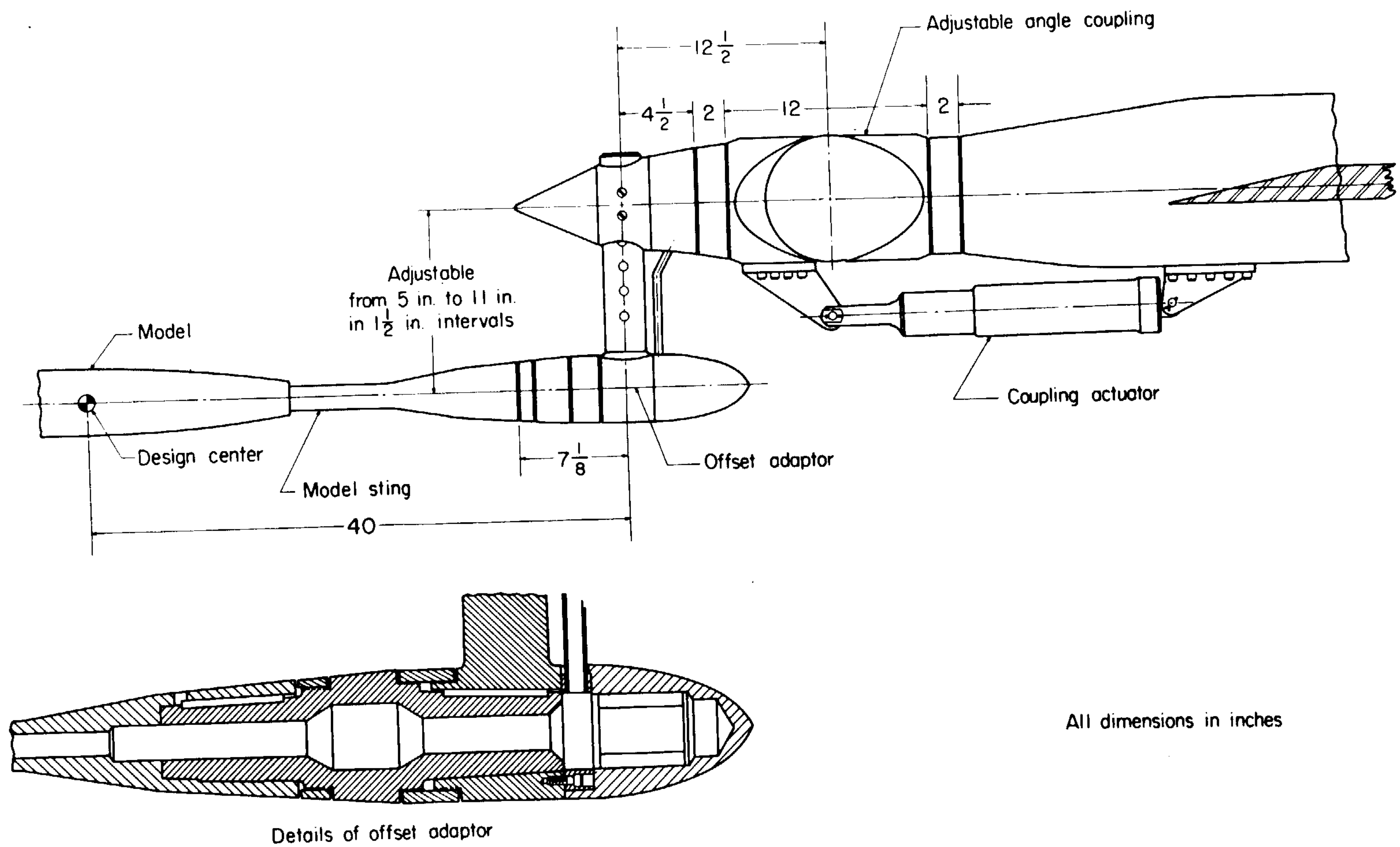


Figure 5. - Alternate support system, Langley Unitary Plan Wind Tunnel.

$$\left.\begin{array}{ll} \dfrac{D_S}{D_B} & < 0.70 \\[2ex] \dfrac{D_S}{D_{Max}} & < 0.40 \end{array}\right\} \text{Use smaller value}$$

$$\frac{l}{D_{Max}} > 2.0$$

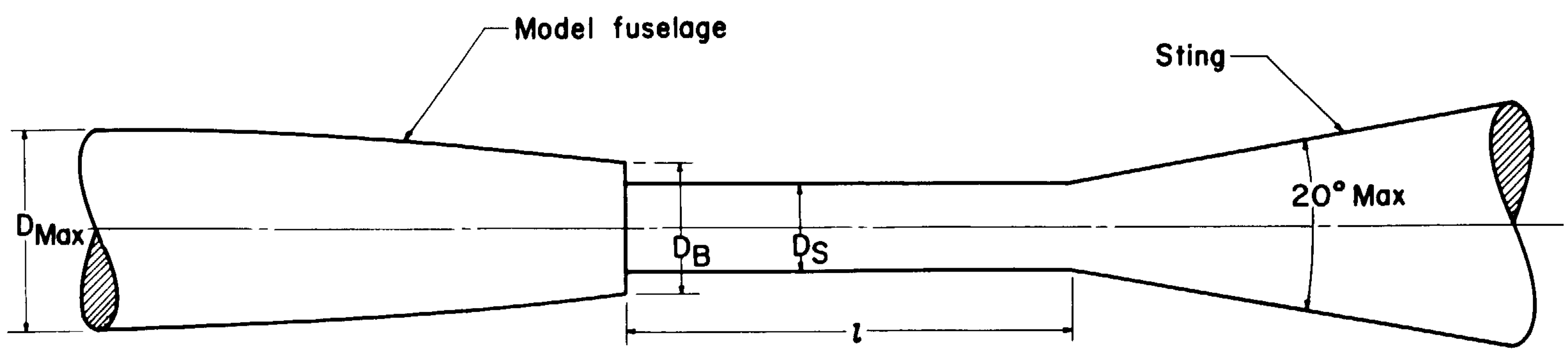


Figure 6. - Details of sting at the model, Langley Unitary Plan Wind Tunnel.

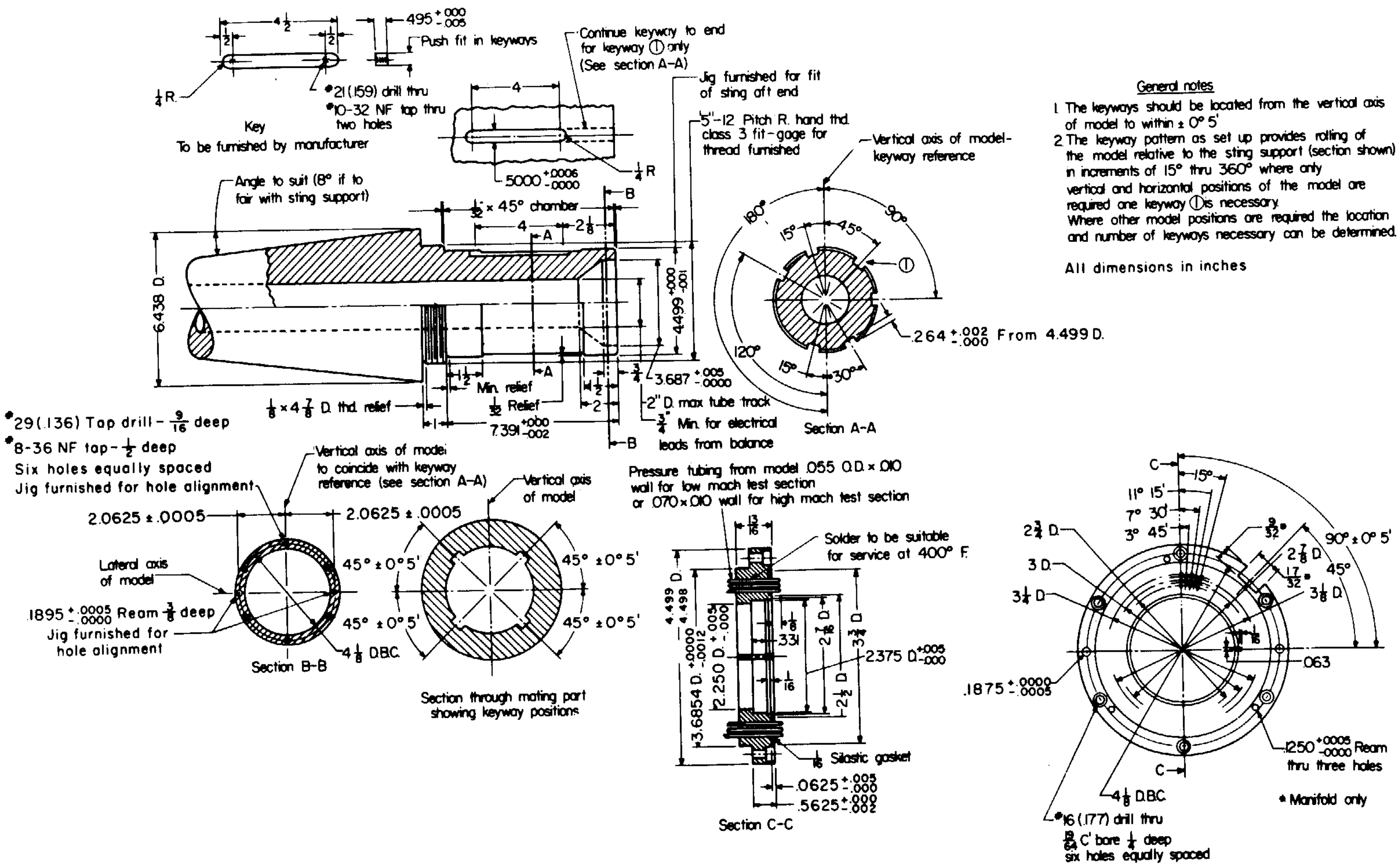


Figure 7. - Model sting (portion) to mate with basic sting support, Langley Unitary Plan Wind Tunnel.

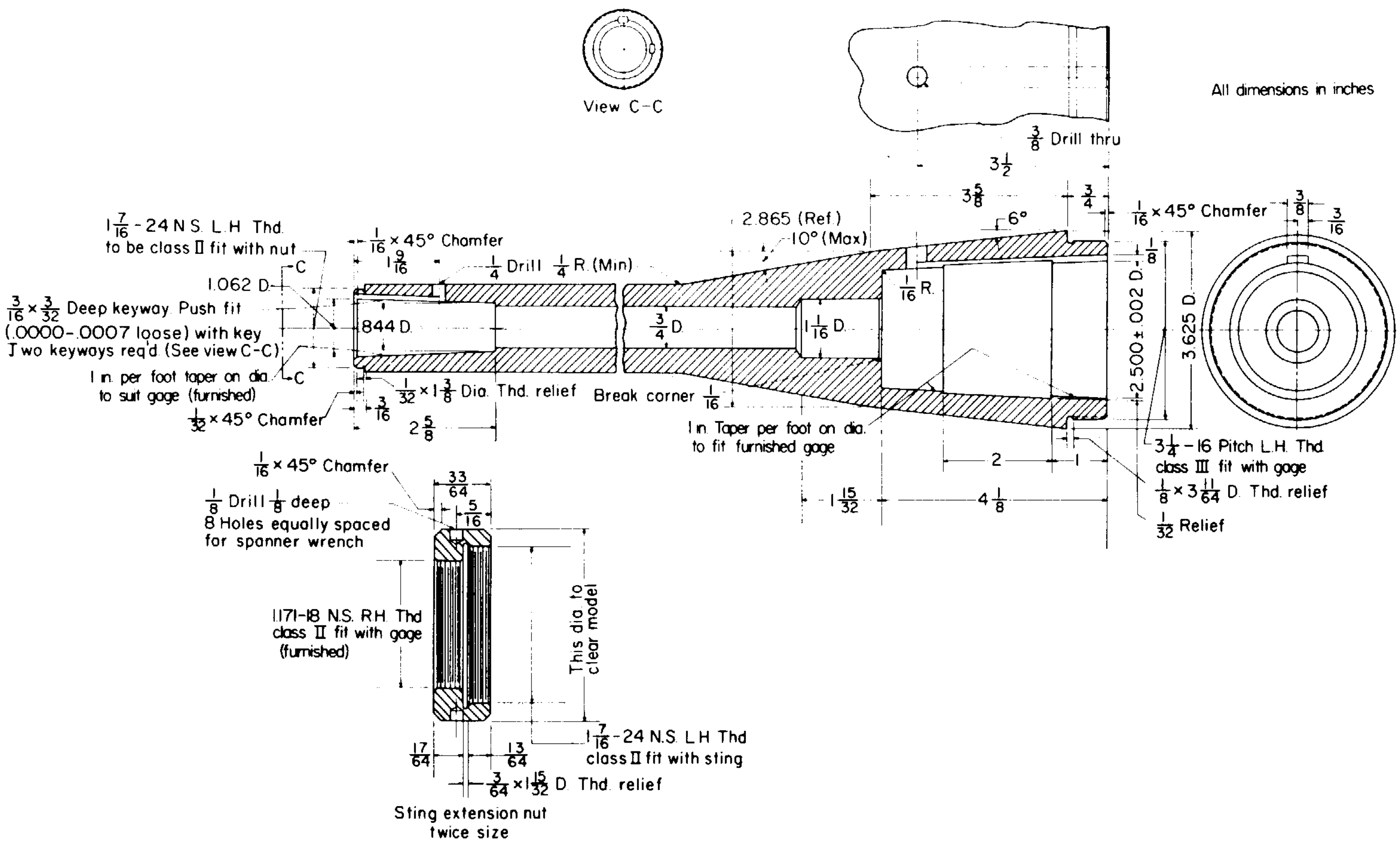


Figure 8. - Model support sting for alternate support system, Langley Unitary Plan Wind Tunnel.

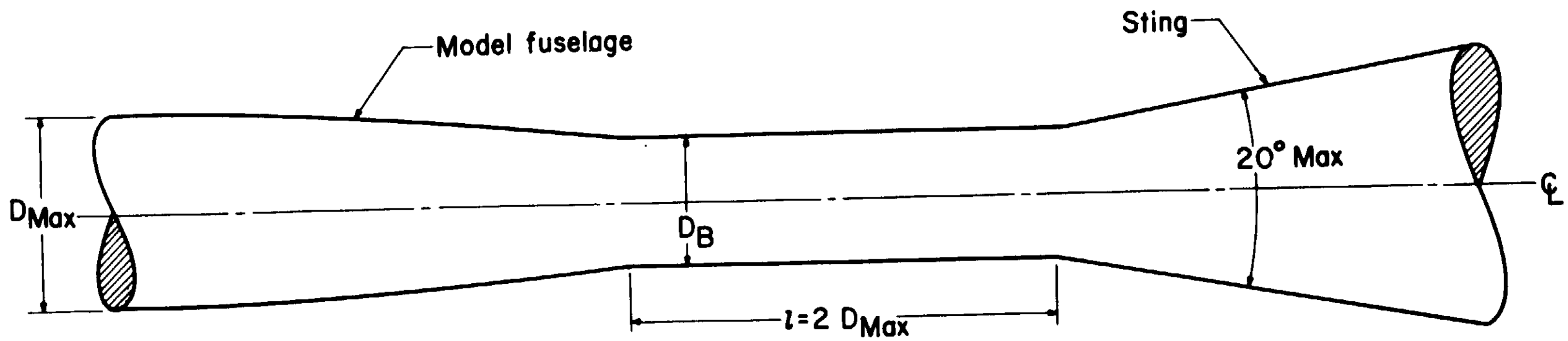
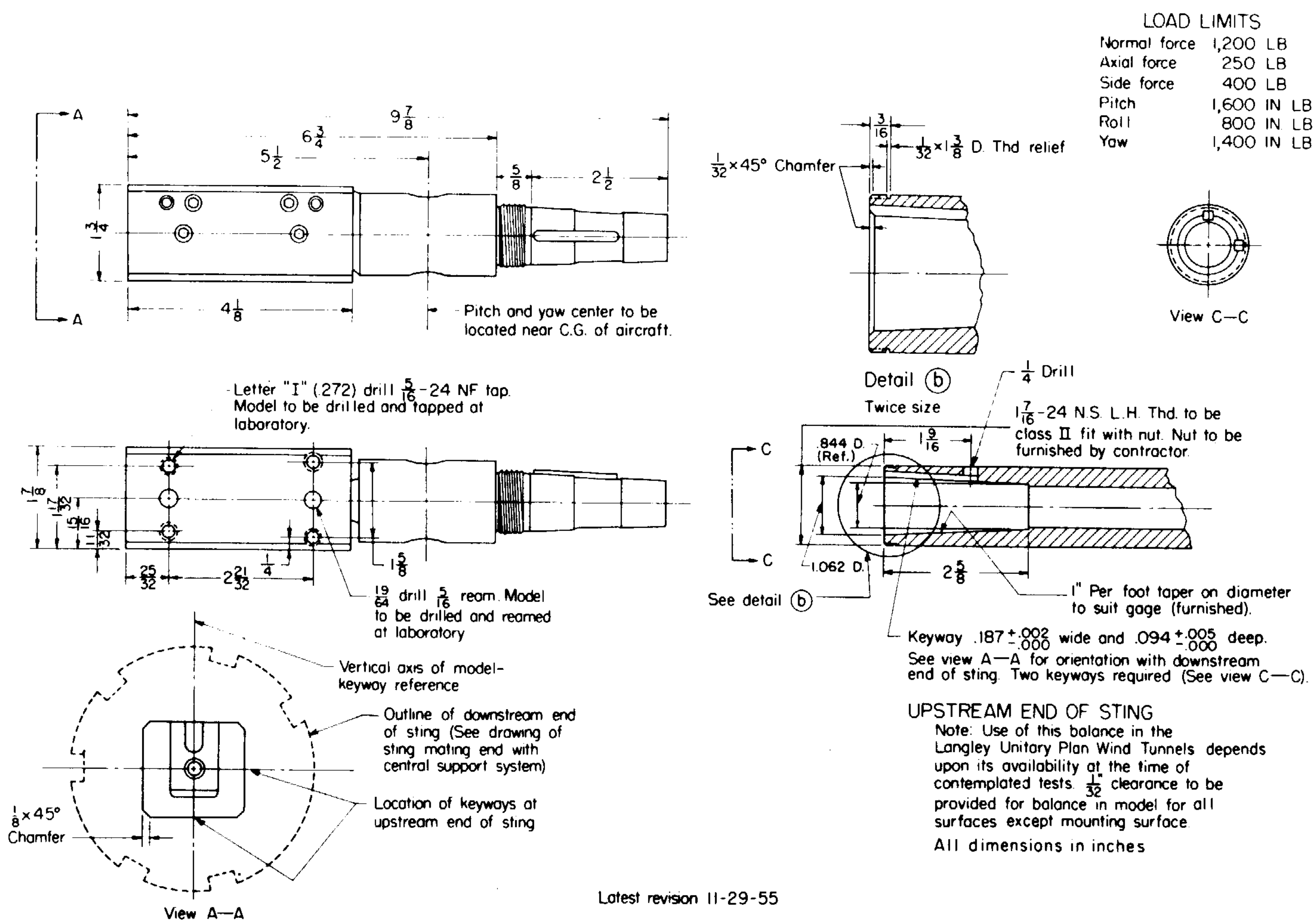
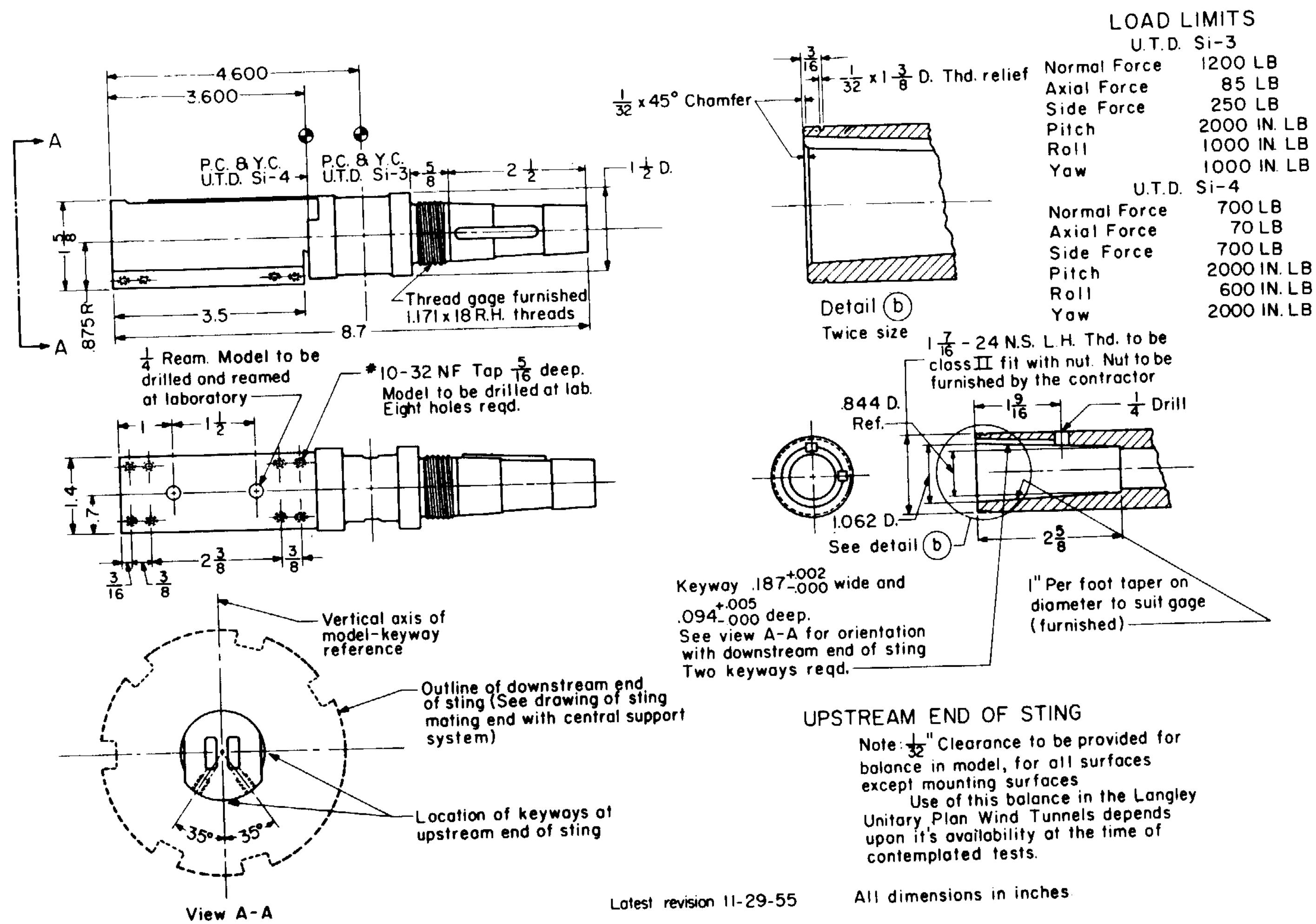


Figure 9. - Recommended attached sting for pressure models, Langley Unitary Plan Wind Tunnel.



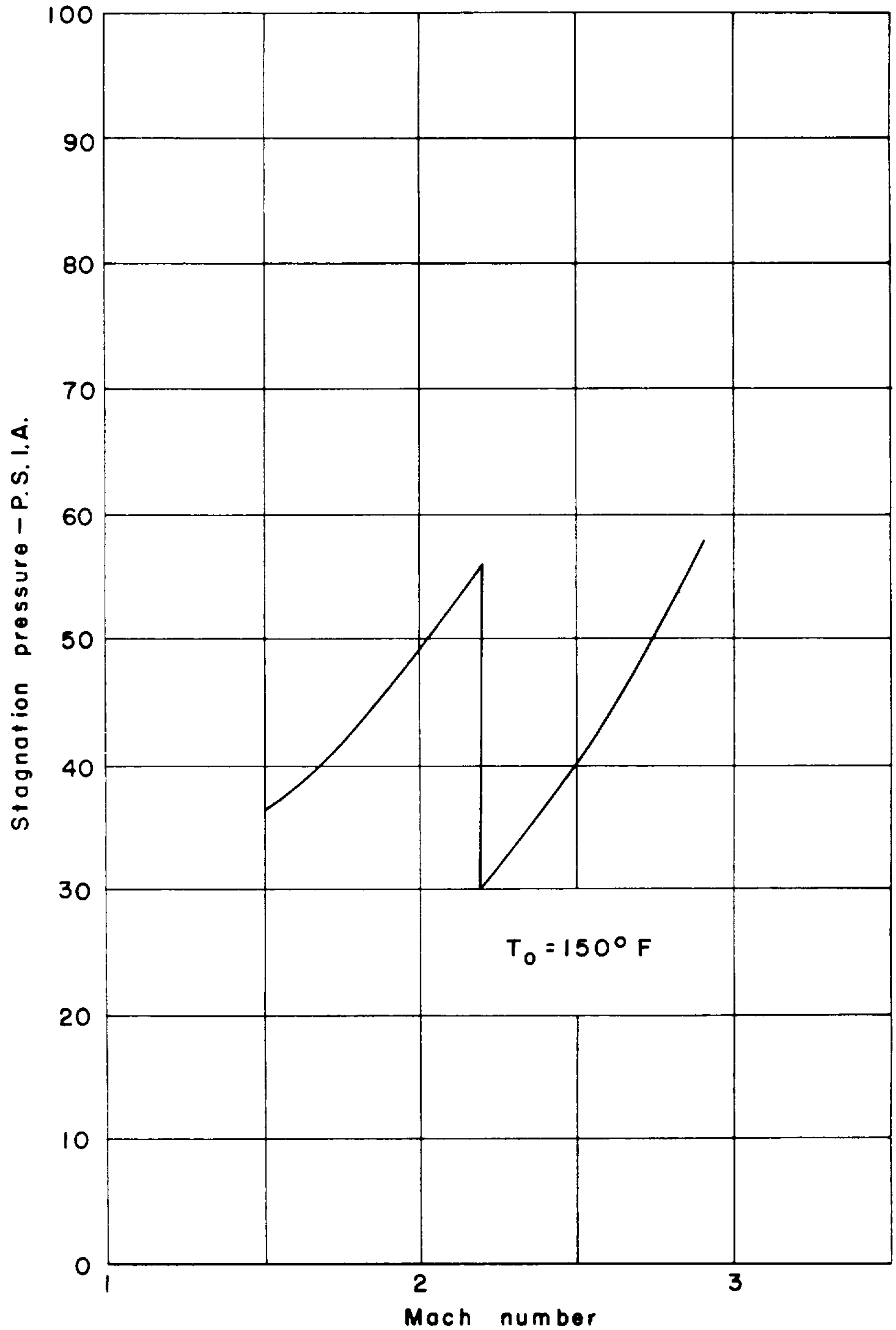
(a) 403.

Figure 10. - Typical NACA balances, Langley Unitary Plan Wind Tunnel.



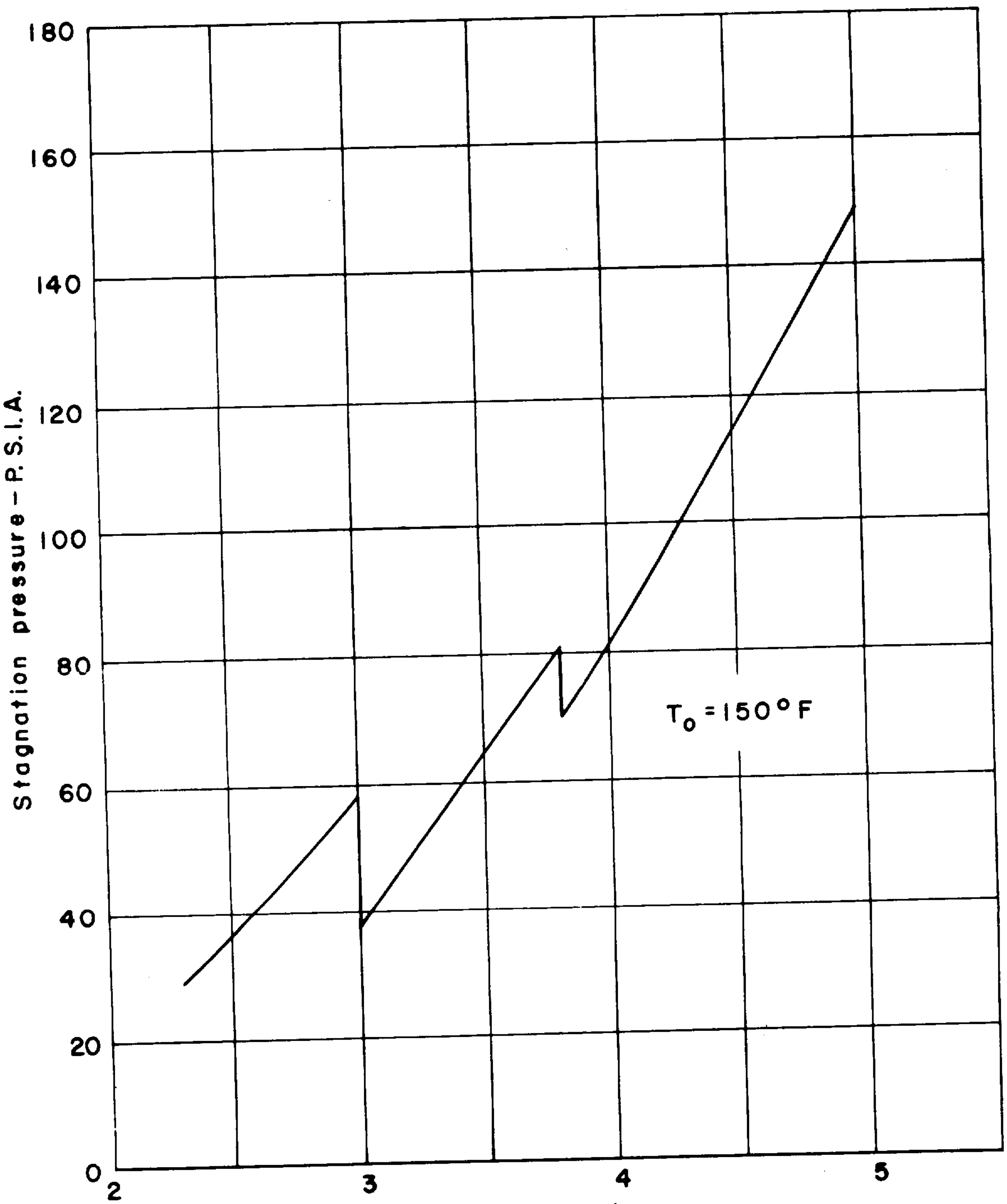
(b) U.T. 03 and 04.

Figure 10. - Concluded.



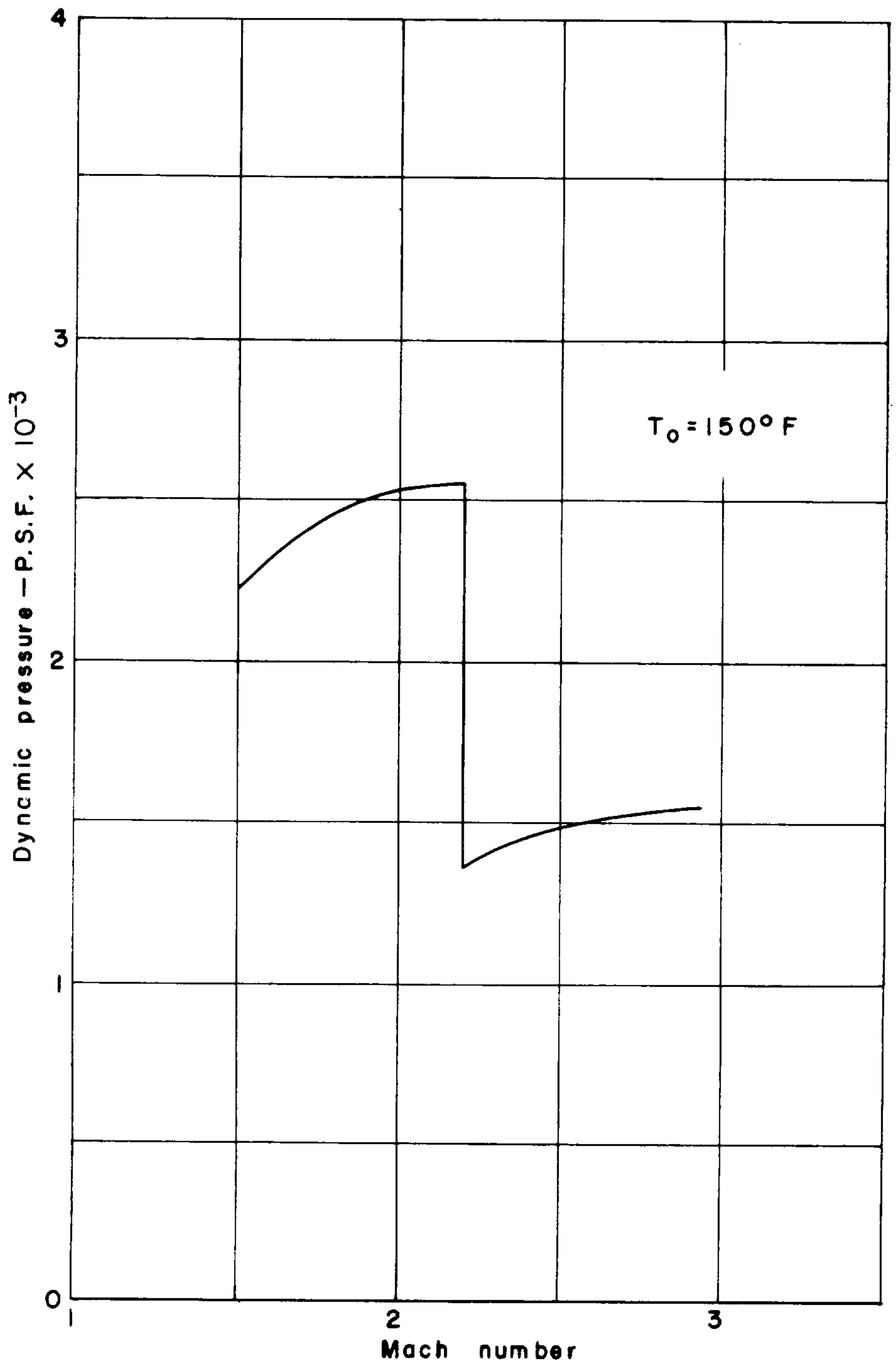
(a) Low Mach number test section.

Figure 11. - Maximum estimated stagnation pressures, Langley Unitary Plan Wind Tunnel.



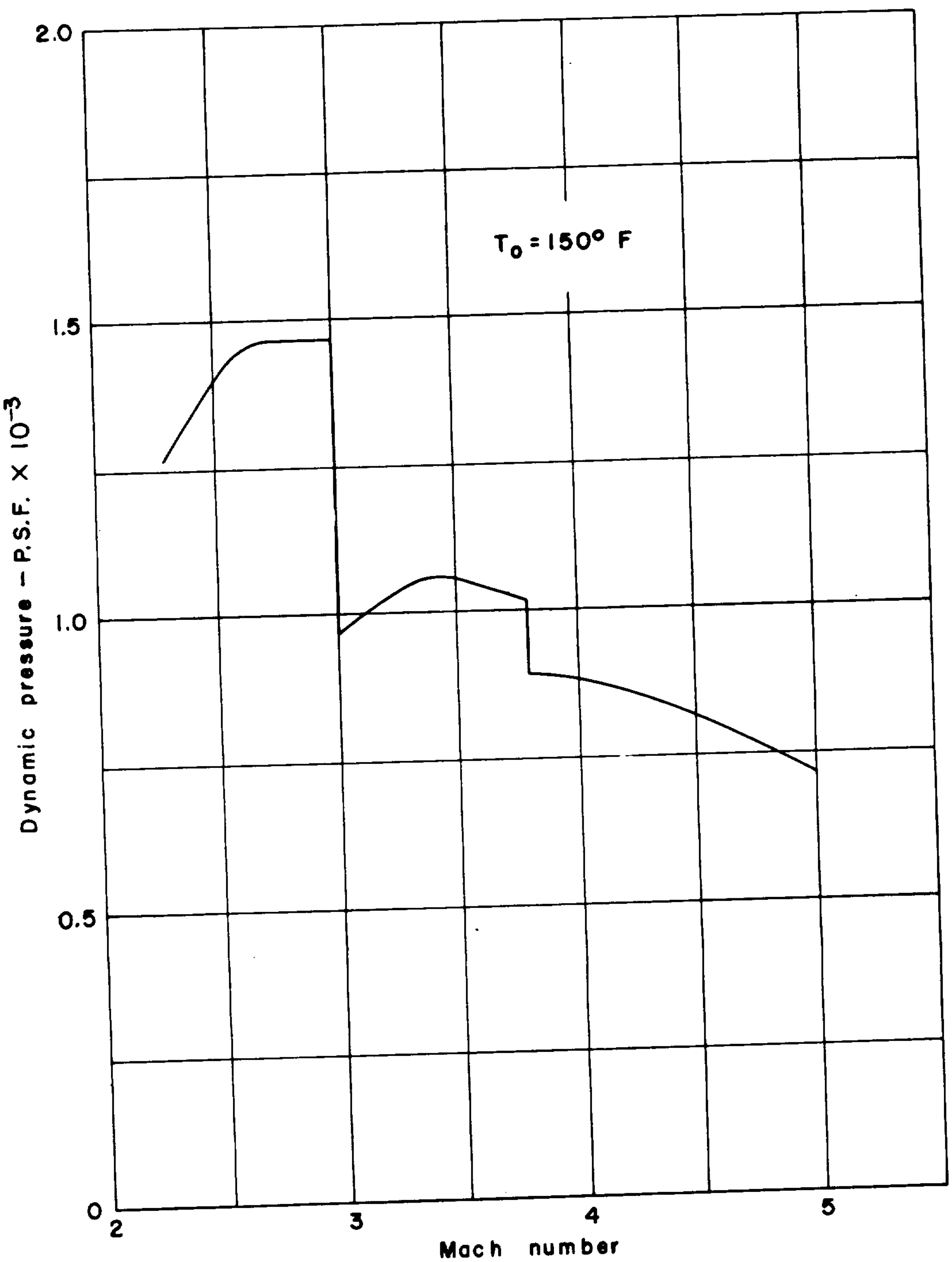
(b) High Mach number test section.

Figure 11.- Concluded.



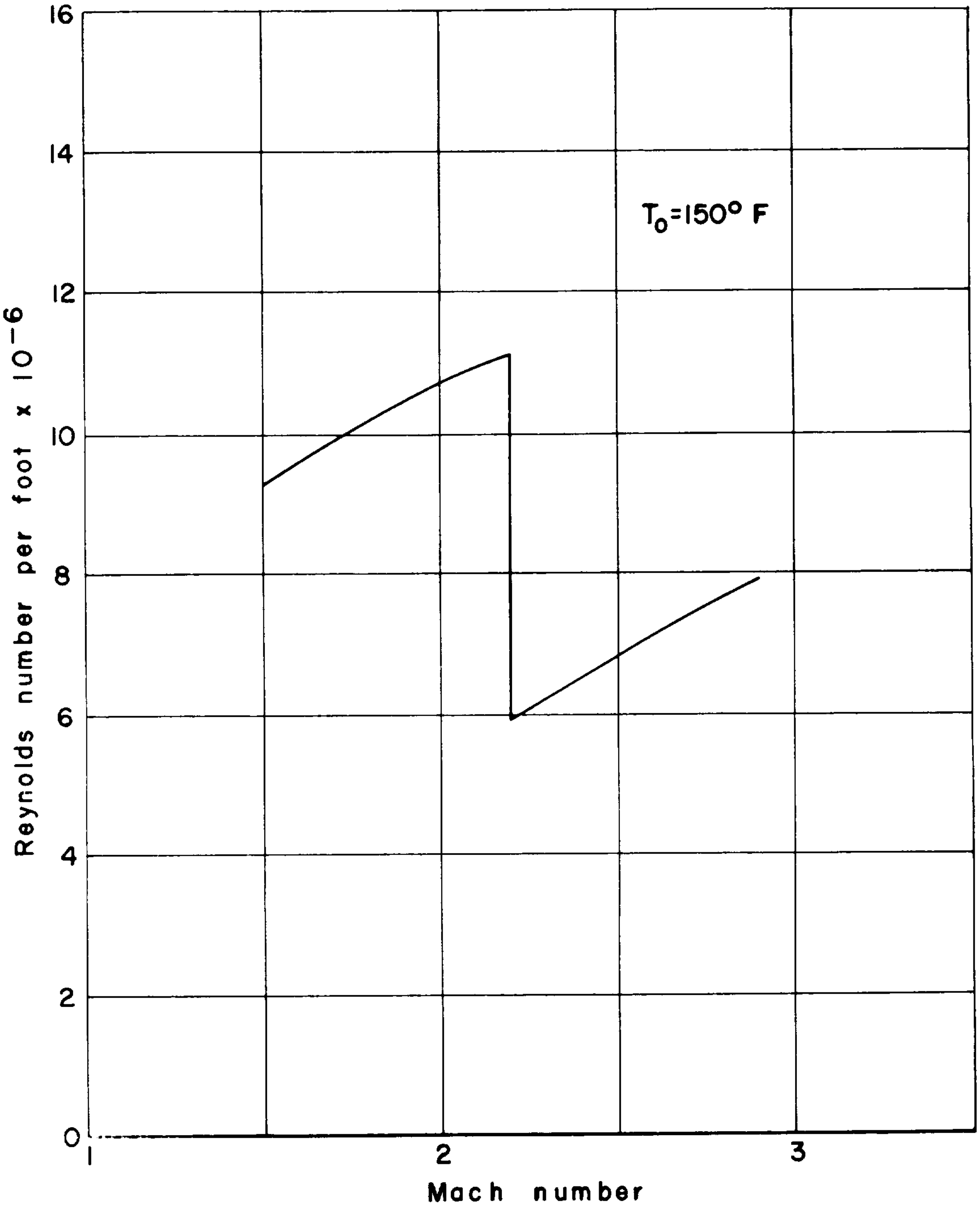
(a) Low Mach number test section.

Figure 12. - Maximum estimated dynamic pressures, Langley Unitary Plan Wind Tunnel.



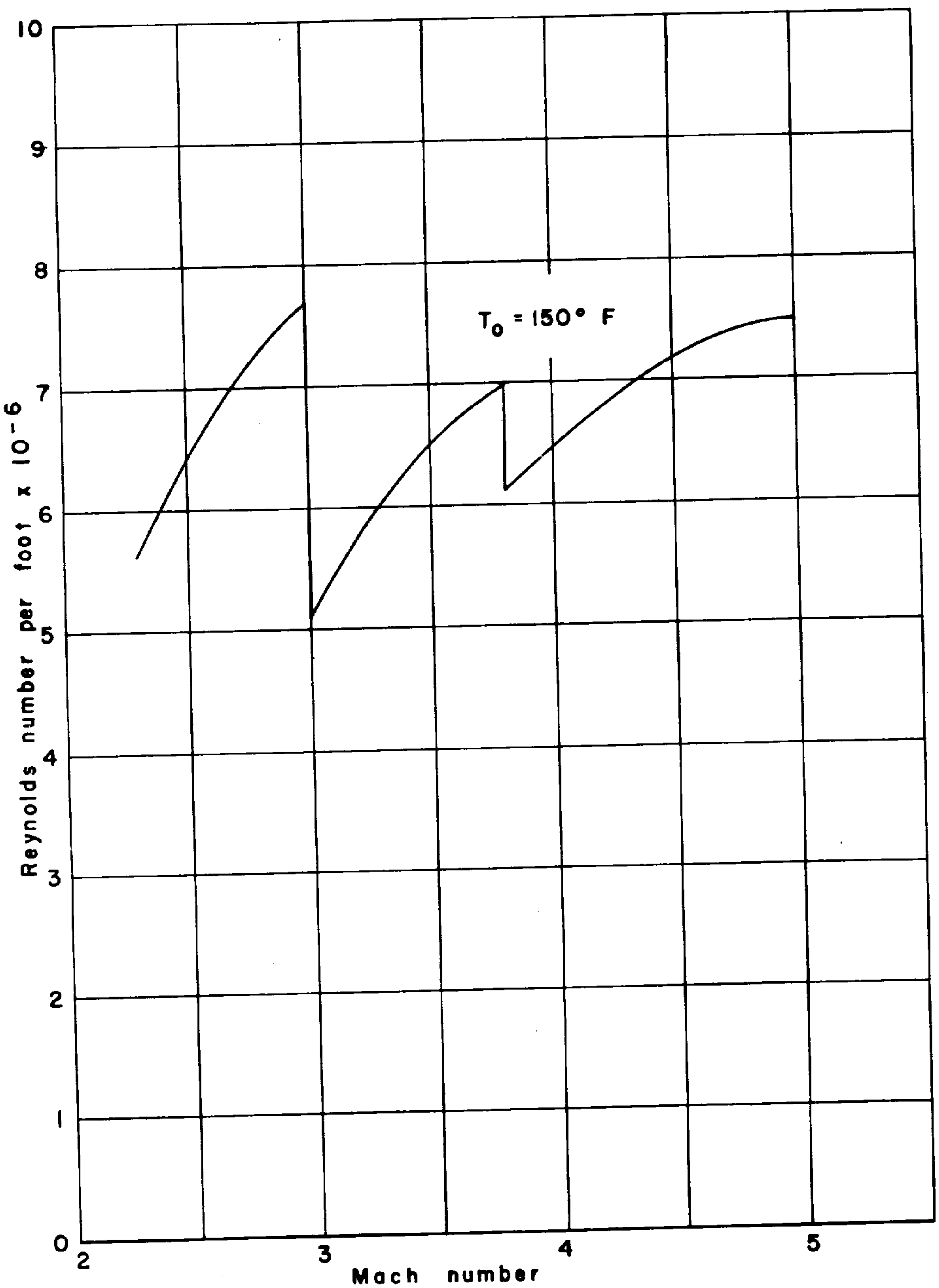
(b) High Mach number test section.

Figure 12. - Concluded.



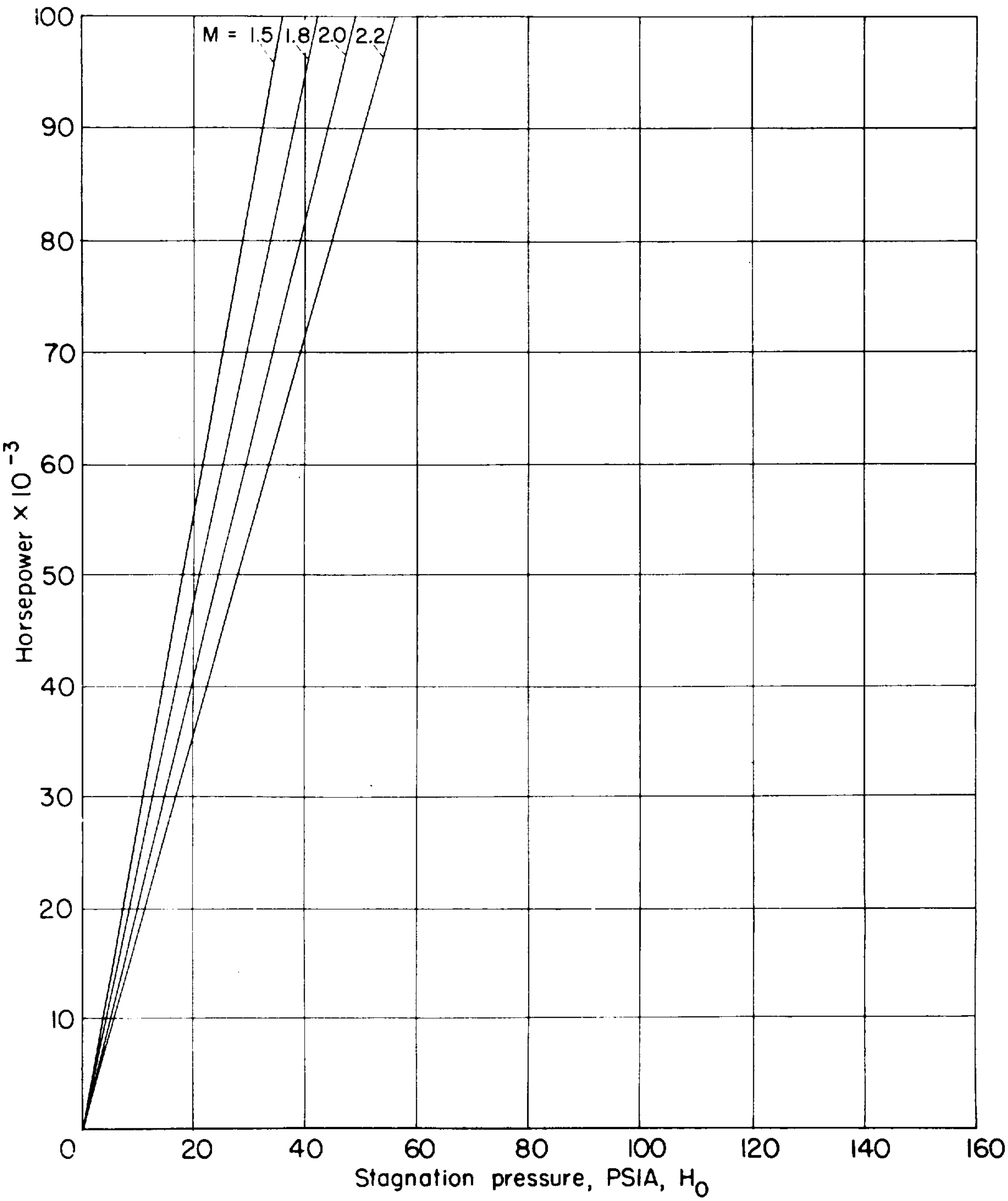
(a) Low Mach number test section.

Figure 13. - Maximum estimated Reynolds number, Langley Unitary Plan Wind Tunnel.



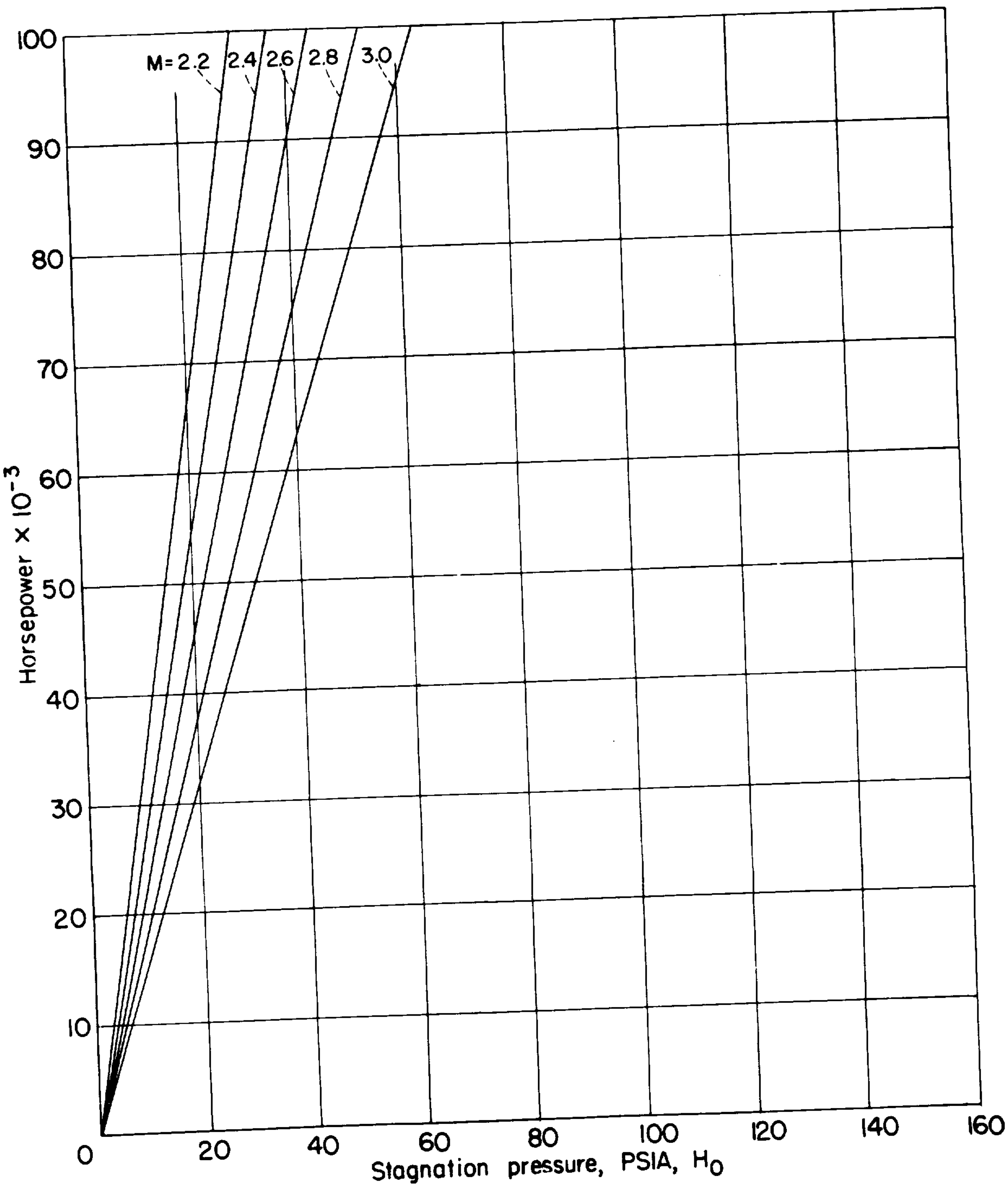
(b) High Mach number test section.

Figure 13. - Concluded.



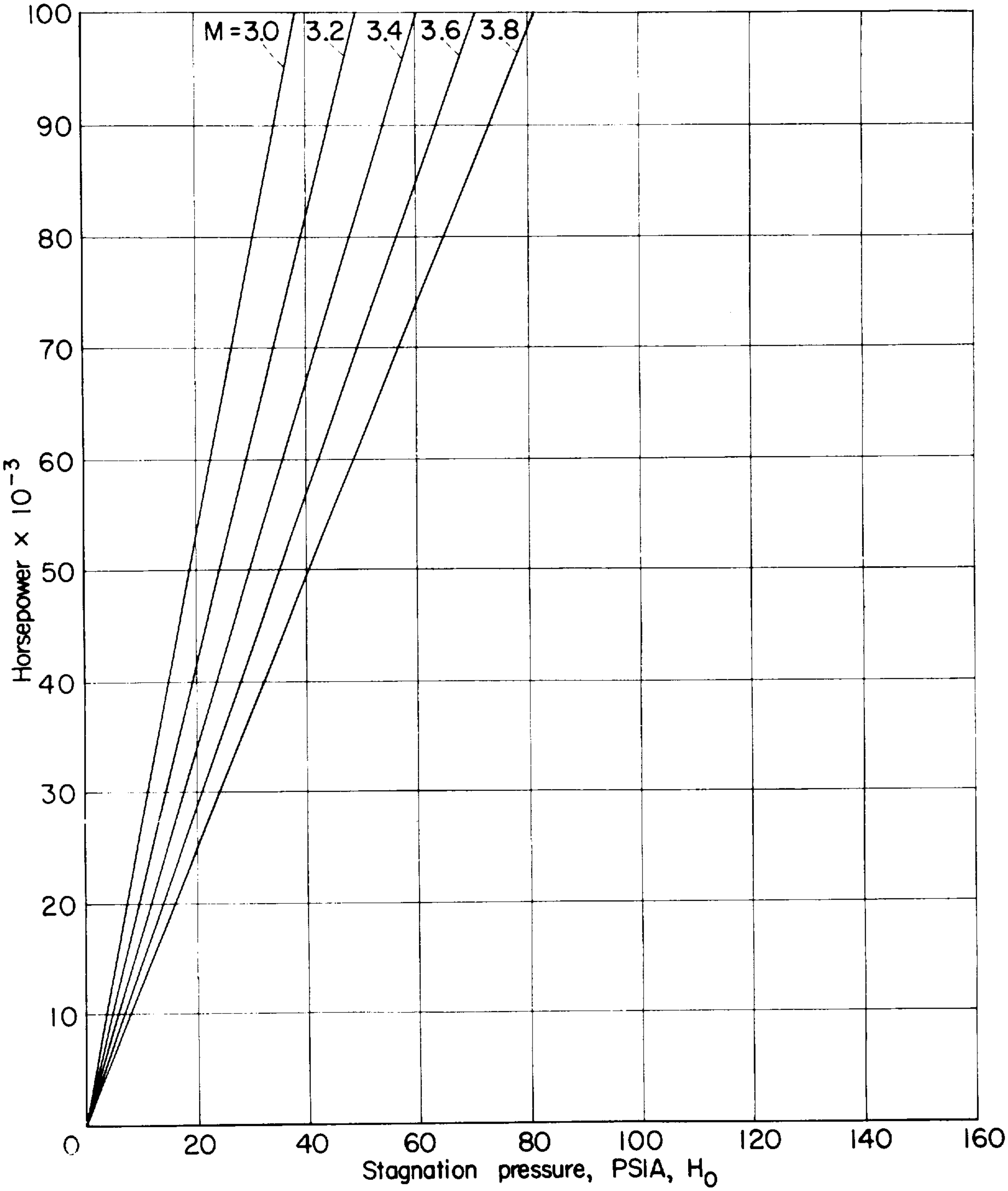
(a) Compressor configuration I.

Figure 14. - Variation of estimated power with H_o and M, T_o = 150°, Langley Unitary Plan Wind Tunnel.



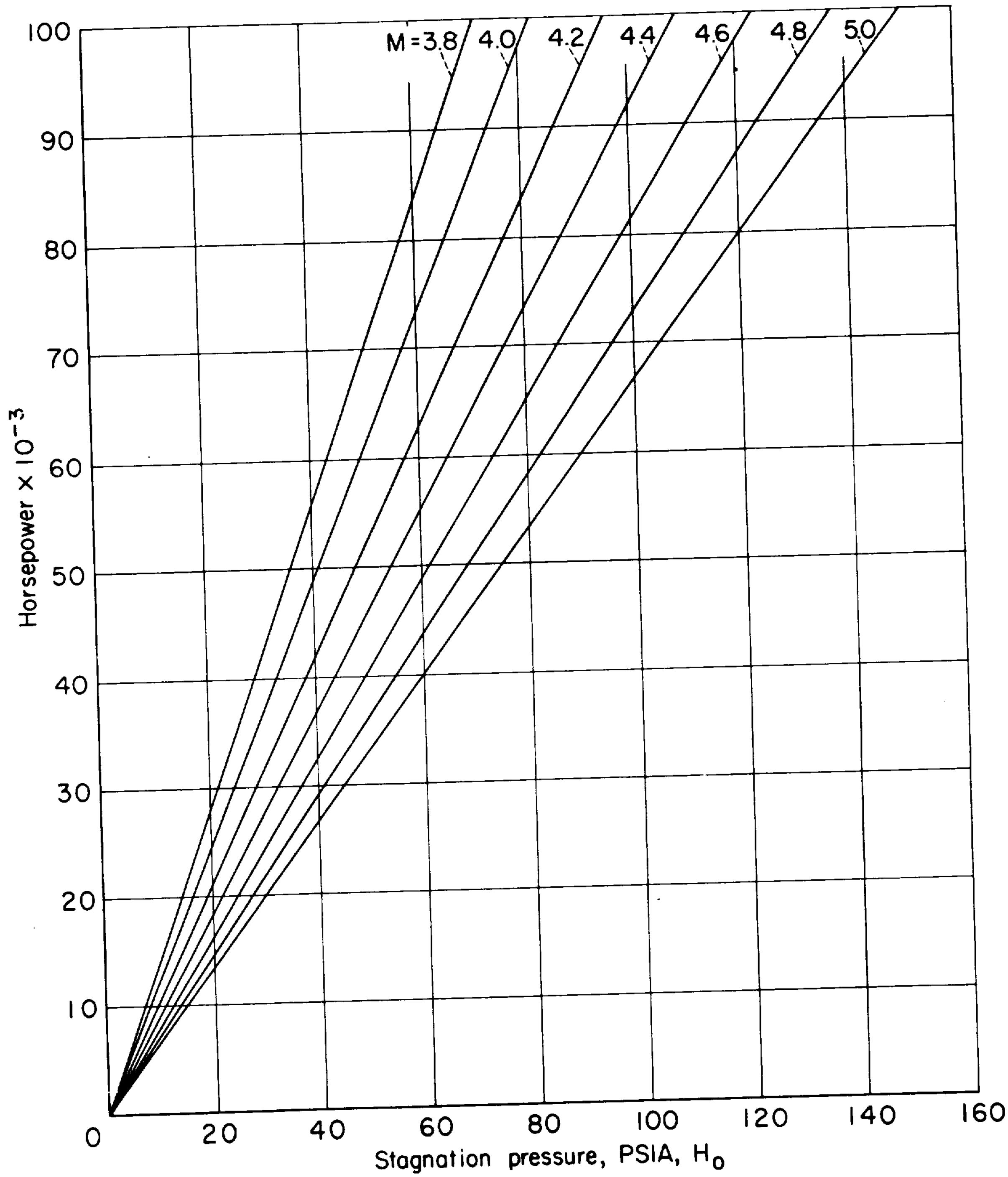
(b) Compressor configuration II.

Figure 14. - Continued.



(c) Compressor configuration III.

Figure 14. - Continued.



(d) Compressor configuration IV.

Figure 14. - Concluded.

THE AMES
UNITARY PLAN WIND TUNNEL

Ames Aeronautical Laboratory
Moffett Field, California

NACA

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THE AMES UNITARY PLAN WIND TUNNEL

GENERAL DESCRIPTION

The major components of the Ames Unitary Plan Wind Tunnel are shown in figure 1. The facility consists basically of three separate test sections which cover the Mach number range from 0.7 to 3.5 in three steps as follows: the 11- by 11-foot transonic leg, $0.7 < M < 1.4$; the 9- by 7-foot supersonic leg, $1.4 < M < 2.6$; and the 8- by 7-foot supersonic leg, $2.4 < M < 3.5$. The Mach number in each test section is continuously variable within its particular range.

The two supersonic circuits have a common central passage in which is located an eleven-stage axial-flow compressor that provides the flow through either of the two supersonic nozzles. At each end of the common central passage is a large flow-diversion valve which turns the airstream into either of the two supersonic circuits. The transonic airflow circuit is separate from the supersonic circuits and has its own three-stage axial-flow compressor.

Stagnation pressures in the ranges of 2 to 35 and 2 to 30 psia are used in the transonic and supersonic circuits, respectively. Aftercooling is provided in each circuit to maintain the stagnation temperature constant during each test run at a constant Mach number and stagnation pressure. If either the Mach number or the stagnation pressure are changed, the stagnation temperature will change within the extremes of 80° and 150° F.

The three-stage and eleven-stage compressors are both driven by the same combination of four electric motors connected in tandem (see figure 1). Disconnect couplings are provided between the drive motors and each compressor to allow operation of either of the two compressors. The drive motors are wound rotor induction type with combined output of 180,000 horsepower for continuous operation or 216,000 horsepower for a period of one hour.

Dry air for use in the tunnel circuits is stored in the four spherical tanks located near the 11- by 11-foot test section (figure 1). Each tank has a volume of 30,000 cubic feet and is designed to store air at pressures up to 140 psi gage. The air is supplied by a 15,000-horsepower centrifugal compressor located in the auxiliary equipment building. The moisture content of the stored air is 0.00005 pound of water per pound of dry air.

A sound-insulated air-conditioned control room is provided within each of the three test chambers. Control of the wind-tunnel operation and of the test conditions is accomplished from these rooms. Each test section is equipped with schlieren equipment for the study of flow patterns which can be viewed or photographed.

At present only 60-cycle, 110-, 220-, and 440-volt current is available at the test sections. Special arrangements must be made for other supplies.

THE 11-BY-11 FOOT TRANSONIC TEST SECTION (M=0.7 TO 1.4)

Continuous variation of the test section Mach number through the range 0.7 to 1.4 is achieved through control of the compressor speed and adjustment of the nozzle side walls. All walls of the test section are slotted to provide control of the shock-wave reflection. The test section is square, 11 feet by 11 feet, and is 22 feet long. The traversing strut which supports the sting body is mounted vertically downstream from the test section (figure 2). This figure also shows the position of the model with respect to the schlieren windows.

Variation of the angle of attack occurs in the vertical plane and sideslip in the horizontal plane. As indicated in figure 2, the center of rotation of the model is kept essentially in the horizontal center plane of the test section by traversing the support strut as

the angle of attack is changed. The center of rotation of the model moves streamwise as the angle of attack is varied. Typical movement of the model center of rotation as the angle of attack is varied from 0° to 15° is shown in figure 2.

Model installation is to be accomplished through the access hatch in top of the test section (figure 3) with a 5-ton capacity traveling crane. A personnel access door (not shown) is provided in the side wall of the diffuser downstream of the traversing strut.

THE 9-BY-7 FOOT SUPERSONIC TEST SECTION (M=1.4 TO 2.6)

The nozzle in this test section is of the asymmetric sliding-block type in which the variation of the test section Mach number is achieved by translating in the streamwise direction the fixed contour block which forms the floor of the nozzle. The test section of this nozzle, shown in figure 4, is 9 feet wide and 7 feet high. The upstream limits of the test section are defined by the Mach lines shown in figure 4. The traversing strut which supports the sting body is mounted horizontally in this tunnel so that variations in angle of attack occur in the horizontal plane and variations in sideslip angle in the vertical plane. The center of rotation of the model is kept in the vertical center plane of the test section by traversing the support strut as the angle of attack is varied. The streamwise travel of the center of rotation of a model mounted on a straight sting for a change in angle of attack of 0° to 15° is approximately 4 inches (figure 4). As indicated in the elevation view, the model center of rotation in pitch moves off the horizontal center plane of the test section with the introduction of angles of sideslip.

Two glass windows are mounted in each side wall of the test section for use with the schlieren equipment. Each of the windows is 2.35 feet in diameter and is mounted off center in a large circular steel disk which can be rotated about its center (figure 4). Rotation of the large disks provides schlieren coverage of two regions each 4.23 feet in diameter.

Installation of models is to be accomplished through the removable hatch in the top of the test section shown in figure 5. A personnel access door (not shown) is provided in the side wall of the diffuser downstream from the trailing edge of the traversing strut.

THE 8-BY-7 FOOT SUPERSONIC TEST SECTION (M=2.4 TO 3.5)

The nozzle in this circuit is of the flexible plate type, with fixed upper and lower plates and flexible side walls. The test section shown in figure 6 is 8 feet high and 7 feet wide. The upstream limits of the test region vary with Mach number and are defined by the Mach lines shown in figure 6. The traversing strut which supports the sting body is mounted vertically in this tunnel so that variations in angle of attack occur in the vertical plane and variations in sideslip angle in the horizontal plane. The mechanical arrangement of the traversing strut and sting body is similar to that for the other circuits so that the movement of the center of rotation of the model is kept to a minimum.

The arrangement of schlieren windows is similar to that in the 9- by 7-foot circuit so that schlieren coverage of either of the two regions indicated can be obtained.

Model installation will normally be made through the opening provided by removal of the test section side wall on the north side of the tunnel (figure 7). Access through removal of the south side wall is possible if required. A 3-ton-capacity overhead crane is available for initial handling of the models with a special dolly to be used for final installation within the test section. A personnel access door (not shown) is provided in the diffuser just downstream of the trailing edge of the injector flaps.

Provision has been made for a limited longitudinal movement of the traversing strut and sting body in the 8- by 7-foot circuit; however, movement of the assembly can be accomplished only when the tunnel is shut down. It is anticipated that the assembly will normally be mounted in the upstream position to allow the use of short stings. The strut is shown in its most rearward position in figures 6 and 7, and can be moved upstream 2.90 feet in approximately 3-inch increments.

MODEL SUPPORTS AND STINGS

MODEL SUPPORTS: Each test section is provided with a model-support system for sting-mounting models. The model support consists of a central sting body mounted on a traversing strut (figure 8). This general arrangement is employed in all three test sections. Although the details of the traversing struts and the lengths of the central sting body differ in each of the test sections, identical mounting heads to which the model-support sting attaches are used to allow transfer of models and stings from one test section to another. The mechanism which provides angle-of-attack and angle-of-yaw variations is also identical for the three test sections so that the available motion of the sting-mounting head is the same for all test sections. The motion of the sting-mounting head is such that with a straight sting any combination of angle of attack, α, and sideslip angle, β, that falls within circle A of figure 9 can be achieved. For example, with a straight sting, if $\beta = 0^{\circ}$ the angle-of-attack range is $\pm 15^{\circ}$. Also, for $\beta = 10^{\circ}$ the angle-of-attack range is approximately $\pm 11^{\circ}$.

The ranges of α and β available may be altered by using a bent sting. The effect is simply to shift the circle defining the limits of α and β by the amount of the bend. Thus, for a 15° bent sting for which all of the bend occurs in the angle-of-attack plane, the maximum values of α and β available are defined by curve B of figure 9. For $\beta = 0^{\circ}$, the angle-of-attack range is 0° to 30°, for $\beta = 10^{\circ}$ the angle-of-attack range is approximately $+4^{\circ}$ to $+26^{\circ}$. For winged models the usable range of sideslip angles may be less than that provided by the motion of the sting-body head. For zero sideslip, the center of rotation of the model is kept on the test section center line by suitable translation of the traversing strut which supports the sting body. However, the model moves toward one of the tunnel walls with the introduction of angles of sideslip. Hence, to avoid interference from the shock waves reflected from the tunnel side wall the maximum sideslip angle that can be used may be less than the 15° available from the motion of the sting-body head.

STINGS: The geometry of the required sting supports will be greatly influenced by the model shape, angle-of-attack and sideslip angles desired; hence, sting details must be arranged between the user and Ames Unitary Plan Wind Tunnel for each proposed test. The sting-body heads to which the stings will attach (shown in figure 8) are identical in all three tunnels. Detailed drawings and a master gage of the sting-body heads will be supplied upon request. It is anticipated that the Ames Unitary Plan Wind Tunnel will provide a number of standard stings which will be available for use by users. Detail drawings of these stings will be available upon request. If the sting is to be supplied by the user, complete drawings and stress analysis of the sting shall be delivered to Ames Unitary Plan Wind Tunnel not less than five weeks prior to the scheduled starting date of the tests. The completed sting shall be delivered to the Laboratory not less than three weeks prior to the scheduled starting date. Preliminary information on stings and adapters available at the Ames Unitary Plan Wind Tunnel is included in figures 14 through 21.

MODEL INFORMATION

DELIVERY: The model shall be delivered to the Ames Unitary Plan Wind Tunnel at least three weeks prior to the scheduled starting date of the tests.

MODEL SIZES: The actual dimensions of models to be used depend upon so many factors that each case must be considered separately. Nonetheless, the approximate maximum dimensions of a typical model for each of the test sections are listed in the following table:

	11- by 11-foot[1]	9- by 7-foot	8- by 7-foot
Body diameter	8 inches	8 inches	8 inches
Body length	8 feet	8 feet	8 feet
Wing span	5.5 feet	3.5 feet	3.5 feet

[1] The ratio of model frontal area to test section area should not exceed 0.005 to insure a minimum of interference.

MODEL STRENGTH: A stress analysis of the model (and balance and sting if supplied by the user) based upon the maximum loads anticipated in the tests shall be submitted to the Ames Unitary Plan Wind Tunnel no less than five weeks prior to the scheduled starting date of the tests.

The maximum allowable stresses for the critical loading conditions shall not exceed one-fifth of the ultimate strength or one-third of the yield, whichever is least. In addition, for members loaded as columns, the Euler critical load shall be at least three times the applied load.

The starting loads shall be assumed to be twice those resulting from the maximum steady-state dynamic pressure in each circuit for starting at 5 psia. The maximum steady-state dynamic pressures for starting at 5 psia may be taken as:

11- by 11-foot	310 pounds per square foot
9- by 7-foot	310 pounds per square foot
8- by 7-foot	200 pounds per square foot

All auxiliary parts of the model which will be exposed to the airstream and are nominally at zero angle of attack shall be checked to at least $\pm 2^{\circ}$ angle of attack at the highest dynamic pressures anticipated in the tests.

The results of static proof tests may be presented in lieu of stress analyses, with the following requirements: for cases in which the aerodynamic load is to be directly and continuously monitored, the static loading shall be carried to twice the maximum predicted load; for cases in which the aerodynamic load will not be monitored, the static tests shall be carried to three times the maximum predicted load. Plots of deflection as a function of load for a complete loading cycle shall show no permanent set.

FUSELAGE SPECIFICATIONS: The fuselage shall be constructed of steel, dural, or suitable plastic to withstand contemplated loads, pressures, and temperatures, yet be as light as feasible. The clearance between the fuselage and the sting will depend on the deflection characteristic of the balance and cannot be specified herein. An effort should be made to electrically indicate fouling between the sting and the model.

It is possible that the fuselage, especially in the case of multiengined models, boat tails to a point or a wedge at the aft end. In order to provide for a sting in such cases, the fuselage may be distorted out of true contour. The region of such distortion shall be kept to a minimum.

WING AND TAIL SPECIFICATIONS: Wing and tail surfaces shall be made of steel to minimize aeroelastic effects and be polished. Tail surfaces shall be made easily removable. Means of adjusting the angular position of the horizontal tail shall be provided.

CONTROL SURFACE SPECIFICATIONS: In order to make the most effective use of tunnel testing periods, those surfaces which are to be deflected during the tests shall be provided, wherever possible, with remote actuation and position indication.

Where hinge moments are to be measured, the control surfaces shall be provided with hinges having a minimum of friction, and with strain gages for measuring the hinge moments.

PRESSURE ORIFICE SPECIFICATIONS: All pressure orifices shall be flush and perpendicular with the external surfaces and shall be not less than 0.040 inch I.D.

SPECIAL CONSIDERATIONS FOR MODELS FOR INLET INVESTIGATIONS: Models designed for inlet investigations shall, in general, be constructed as described above. The model body shall duplicate the full-scale configuration for sufficient distance to assure inlet and boundary-layer flows corresponding to the full-scale configuration. All canard sur-

faces and other appurtenances to the forebody shall be included. Ducts through the fuselage or nacelles shall be simulated to the extent that air can flow through them with the design mass-flow ratio. Mass flow shall be controlled by choking a nozzle in the model. In scaling down the model any boundary-layer bleeds shall be modified to correct for the difference in Reynolds number. Provision shall be made for the installation of dynamic pressure pickups on the model at locations such that indication of incipient flow instability (buzz) can be obtained. The dynamic pickups will be furnished by the NACA. Rakes shall be located in the model to determine pressure recovery and pressure losses at the duct exit, and mass-flow ratio. These rakes shall have tubes of at least 0.035 inch I.D. and the tubes shall be rigidly supported. All soldering on the rakes shall be silver soldering and the tubes shall be made of stainless steel. Rakes should be made so that tubes measure equal areas of the duct in order to facilitate pressure integration. Normally, the mass-flow ratio shall be determined by calculations based on the integrated pressure readings. In some instances, where justified, the internal flow will be piped out of the rear end of the model into a flowmeter which contains a measuring orifice and a remotely adjustable valve to vary the flow. This flowmeter will be furnished by NACA.

MISCELLANEOUS: All removable parts shall have a minimum of small wood or metal screws, and shall be doweled for accurate replacement.

All pressure tubes and electrical leads from the model shall be readily accessible to facilitate installation and maintenance in tunnel.

All screw heads on the surface of the model shall be filled with materials which will withstand the temperatures at which the tests will be conducted. Hard wax will be satisfactory for temperatures under 150° F. Duratite, phenoline, or similar materials should be used at higher temperatures.

INSTRUMENTATION AND DATA PROCESSING

BALANCES: Internal strain-gage balances will normally be used for measuring the forces and moments on models. The balances to be furnished by Ames Laboratory are in the design stage. Preliminary data on their dimensions and load limits are included in figures 14 through 21. Calibrations will be available at a later date.

If balances are to be supplied by the user, drawings, stress analyses, and complete calibration data shall be delivered to Ames Unitary Plan Wind Tunnel at least five weeks prior to the scheduled starting date of the tests. The balance shall be delivered to the Ames Unitary Plan Wind Tunnel not less than three weeks prior to the scheduled starting date.

The details of instrumentation for measuring component factors such as hinge moments or individual panel loading should be arranged with the Ames Laboratory for each test. Ordinarily, strain gages are used for these purposes. A permanent installation is provided at each test section for indicating and recording ten channels of strain-gage data. Six channels may be used for the outputs from the internal strain-gage balance and four channels for hinge-moment measurements.

PRESSURE MEASUREMENTS: Pressure-distribution models will normally be mounted on a hollow sting. The pressure leads will pass through the hollow sting into the sting body and thence through the cutouts in the traversing strut (figure 8) to the wall of the pressure capsule surrounding the model-support mechanism. A pressure-tight junction block provides for passage of the leads through the tunnel shell and thence to either multiple tube manometer boards or electrical pressure pickups. Approximately 200 pressure leads can be accommodated through the 2-inch-diameter hole in the sting-body head.

Three 64-tube manometer boards are available for use. The boards have a usable height of 84 inches and scales with 0.1 inch least division. The glass tubing has a nominal inside diameter of 5 mm. Stainless-steel manifolds and Dekoran plastic connectors are used throughout.

DATA PROCESSING: An integrated automatic data reduction system will be available for the Ames Unitary Plan Wind Tunnel. The purpose of this equipment is twofold: first, to enable monitoring both of raw data and the computed results as the test progresses and second, to provide tabulated and plotted data in coefficient form concurrent with operation of the wind tunnel. Approximately two minutes per point will be required for reduction, tabulation, and plotting of data.

The system is shown schematically in figure 10 and consists essentially of analog type sensing elements, analog to digital converters, a high-speed digital computer, and tabulating and plotting equipment. One ten-channel strain-gage recorder is installed permanently in each test section. Visual monitoring of ten channels of strain-gage output is provided. Each of these units has a seventeen-channel printer which provides for printed records of the output of the ten basic channels, six supplementary channels, and one channel which is reserved for run identification. The supplementary channels may be used to print out analog information from transducers which, for example, may be used to indicate angle of attack, angle of sideslip, Mach number, total pressure, static pressure, or base pressure. Although the transducers which provide this supplementary information may consist of several separated units, for simplicity they have been shown in the schematic diagram as a single unit labeled "Supplementary Servos."

One portable recorder similar to the ten-channel units with six dials and printing channels is available for use at any of the test sections.

Also included as permanent parts of the equipment in each test section are an IBM summary punch, Flexowriter, and a plotting machine. The test section summary punch is provided to allow the recording of raw data at the test section in the event of malfunctioning or unavailability of the computer and will therefore be inactive during normal operation of the computer. The test section Flexowriter is a transmitting and receiving electric typewriter used for tabulating the computed coefficients received from the central computer and also for punching this information into a paper tape. The plotting machine will be used for plotting computed data. The machine can be programmed to produce six individual plots of data on the 30- by 30-inch plotting area. For example, six-component data run at several fixed Mach numbers would be plotted on six different systems of axes within the 30- by 30-inch limits with a different symbol being used for each Mach number.

The data processing equipment contained within the central computing room consists of a high-speed digital computer together with the associated conversion, control, and recording equipment. The IBM summary punch will be in the line to record raw data whenever data are being received at the central computing room. The computer receives input data directly from the test section and performs the necessary arithmetic operations required to provide data in coefficient form. The computer output consists of two punched tapes; one tape will be punched within the computer and the other by the attached Flexowriter. The first tape will include all scale factors and zero offsets necessary for plotting. This tape will be read and the information transmitted to the test section plotter by means of the computer tape reader. The data on the second tape will be in coefficient form and will be recorded and transmitted to the test section Flexowriter by means of the computer Flexowriter.

FACILITIES PROVIDED TO USERS

Offices and shops are provided in the central office building for the use of the company's representatives. The offices are approximately 13 feet by 16 feet and will be furnished. The shops are about 28 feet by 38 feet and are equipped with work benches and an overhead 1-ton hoist for handling models. Adequate 110- and 220-volt, 60-cycle power outlets are provided. Air pressure outlets are provided for operation of air-powered tools. Power supplies other than the above must be arranged for in advance. An elevator is provided in the central building for transporting test models between the ground level and the second or third floors. All doors to the company's offices and shops are provided with combination padlocks.

OPERATING CHARACTERISTICS AND POWER COST ESTIMATING

OPERATING CHARACTERISTICS: The calculated maximum values of stagnation pressure, dynamic pressure, and Reynolds number which are expected to be available in each of the three circuits of the Ames Unitary Plan Wind Tunnel Facility are presented in figures 11, 12, and 13. For the two supersonic circuits the maximum Reynolds number is limited by the power available. For most of the Mach number range of the transonic circuit, the structural design pressure of 35 psia limits the maximum Reynolds number.

PURGING OF TUNNEL CIRCUIT: Prior to the start of a test run in any circuit of the facility, it will be necessary to evacuate and purge the circuit. This procedure is required for starting the main drive motors and to obtain the desired humidity conditions in the operating circuit. The 15,000-horsepower auxiliaries make-up air compressing equipment, serving a dual purpose of evacuating the tunnel circuit and supplying compressed air to storage spheres, is used for this purpose.

A typical purging operation of a tunnel circuit will be to evacuate to 1.5 psia and then purge with dry air from the storage spheres to atmospheric pressure. The circuit will again be evacuated to 5.0 psia or lower in preparation for starting the main drive motors. The time required for purging depends upon the circuit involved, the initial humidity conditions, and the final humidity condition desired for the test; however, it is expected that the purging time for any of the circuits will be approximately thirty to forty minutes.

STARTING AND STOPPING MAIN DRIVE MOTORS: Characteristics of the utility power system supplying Ames Laboratory impose a limitation on instantaneous line surge and on the rate of increase or decrease of line load. For this reason all starts of the main motor drive will be made at reduced density as noted above. The acceleration of the motor drive and the increase of circuit density must be controlled to a maximum load increase of 12,000 kilowatts per minute. This limitation results in approximately 2.0 minutes being required to bring the motor drive up to full operating speed with a circuit density of 5.0 psia. To comply with these restrictions the rate of increase in total pressure is limited to a maximum of 2.4 psi per minute in the transonic circuit and 1.1 psi per minute in the two supersonic circuits.

For stopping the main motor drive or for decreasing the circuit pressure the maximum rate of load decrease must be controlled to 18,000 kilowatts per minute. It is anticipated that at the conclusion of a test run the circuit pressure will be decreased to approximately 5.0 psia and then the motor drive stopped. With the limitations imposed, the operating total pressure can be decreased by a maximum of 2.9 psi per minute in the transonic circuit and 1.3 psi per minute in the two supersonic circuits. At a circuit density of 5.0 psia and full operating speed, the main drive motors can be stopped in approximately 1.5 minutes.

POWER COST ESTIMATES: The data presented herein are for the purposes of estimating the costs for electric power necessary for a particular test program in the Ames Unitary Plan Wind Tunnel. Based on the anticipated monthly consumption of the Ames Laboratory during fiscal year 1956, the average rate per kilowatt hour is not expected to exceed 10 mils.

The power required for the main drive during any test period may be estimated by referring to figures 11, 12, and 13 for the maximum test conditions available in the three test sections. The curves shown are for the one-hour maximum overload power rating of 216,000 horsepower. The power required for any other conditions of pressure may be obtained by direct interpolation. In addition 17,000 kilowatts per hour should be added for drive auxiliaries and electrical losses. It should also be noted that runs requiring more than 50,000 kilowatts of electrical demand must be scheduled for off-peak operation between 10:30 p.m. and 6:30 a.m.

A portion of the electrical power required for the operation of this facility will be utilized for the operation of the 15,000-horsepower air-compressing equipment used for evacuation and purging of the wind-tunnel circuits. Evacuation and purging times will vary as noted in the foregoing section; however, for estimating purposes it is believed that an average time of approximately one hour's operation of the auxiliaries compressing equipment will be required for a complete cycle of purging one of the circuits. It is estimated that these operations will consume approximately 6,500 kilowatt hours of electrical energy.

INFORMATION TO BE SUPPLIED BY THE USER

The user shall furnish the following information as soon as possible after the tests have been requested:

I. Model Details and Stress Analysis

A. DRAWINGS OF MODEL

1. Three-view suitable for inclusion in a report
2. One complete set of drawings or sketches providing the following data pertinent to the model:
    a. All configurations to be tested; configurations shall also be listed in tabular form and cross-referenced to drawings
    b. Weight and center-of-gravity location for all configurations
    c. Materials employed in fabrication
    d. Heat treatments
    e. Types of bolts, screws, and other fasteners
    f. Weld dimensions
    g. Special methods of adhesive bonding
    h. Location of suitable reference stations for orientation of model in tunnel, including description of means for determining angular relationships
    i. Location and identification of pressure rakes, probes, and orifices
    j. For models to be tested in the transonic speed range, a diagram shall be provided presenting the model cross-sectional area as a function of distance along the longitudinal axis. Diagram should indicate contributions of removable components so that area distribution for any particular test configuration can be obtained.

B. DRAWINGS OR SKETCHES OF MODEL INSTALLATION: These drawings or sketches shall show the relation between the model, the balance, the sting, and the sting support. The model reference stations identified under the preceding section entitled DRAWINGS OF MODEL shall be used in locating the model with respect to the support system. The leading edge of the traversing support strut shall be taken as the basic reference line for the model support system. References to all detail drawings and subassemblies should be clearly shown.

C. TABULATED DATA: The detailed information listed in table I shall be submitted. (Table I is found following this section.)

D. TEMPLATES: The user shall provide templates of all critical surface contours (such as body and duct contours, airfoil sections, etc.). A surface shall be considered critical if deviations from the prescribed ordinates would influence the test results. The number of templates to be provided is not specified, but should be sufficient to establish the conformation of the surface with the desired ordinates.

E. STRESS ANALYSIS: A stress analysis of the model (and balance and sting if supplied by the user) based upon the maximum loads anticipated in the

tests and on the information supplied in the preceding section on MODEL STRENGTH shall be submitted to the Ames Unitary Plan Wind Tunnel no less than five weeks prior to the scheduled starting date of the tests.

Each section devoted to a detailed analysis shall contain a sketch showing the design forces and moments acting, the general equations for the stress distribution, and a concise statement of the assumptions and approximations involved. Section properties of structural members (both bending and torsion) shall be shown at an adequate number of stations to facilitate a check on the location of the designated critical sections.

As noted under MODEL STRENGTH, the results of static proof tests may be presented in lieu of stress analyses.

F. REVISIONS: The Ames Unitary Plan Wind Tunnel should be notified immediately of any changes to the model, balance, or model-support system which involve the structural integrity of the installation, the test procedure or results, or the instrumentation. Reasons for the revisions should be stated. If the structural integrity is involved, additional stress analysis should be submitted to show satisfactory safety has been maintained.

II. <u>Test Program</u>

A. ITEMS: The proposed test program should include the following items:

1. List of the data desired: e.g., six-component force data, duct-inlet pressure recoveries, mass-flow measurements, control surface hinge moments, pressure-distribution data, etc.
2. Tentative schedule of the tests indicating model configuration (cross-referenced to the table of model configurations), tunnel operating conditions, increments and ranges of the variable parameters, and the data to be taken at each condition.

III. <u>Data Analysis Information</u>

A. MODEL AREAS AND DIMENSIONS: All areas and model dimensions required for computation factors. Tabular form preferred.

B. PLOTTED RESULTS: Desired form of plotted results.

C. COEFFICIENTS AND LOADS: Required force and moment coefficient accuracies and estimated model loads.

D. PRESSURE MEASUREMENT: Required pressure measurement accuracies and estimated extreme values relative to test section dynamic pressure.

E. USER'S BALANCES: For user-furnished balances, all calibration factors and calculative procedures necessary for data reduction.

F. SPECIAL DATA: Schedule of any special data required such as balance calibration, probe calibrations, etc.

SHIPPING ADDRESS

Material shipped to the Ames Unitary Plan Wind Tunnel to be incorporated as a part of a model or test should be addressed as follows:

Ames Unitary Plan Wind Tunnel
NACA Ames Aeronautical Laboratory
Moffett Field, California

A return address and some type of model identification must be attached to the outside of the container.

TABLE I

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

AMES UNITARY PLAN WIND TUNNEL MODEL DATA

Date forwarded ____________

Model designation ____________ Model scale ____________

C.g. location	Longitudinal, ft from L.E. M.A.C.	
	Vertical, ft (above, below) fuselage reference	

Ⓐ Main surfaces

ITEM		Surface: Wing (Total / Exposed)	Horizontal tail (Total / Exposed)	Vertical tail (Total / Exposed)	Canard (Total / Exposed)	Tip control	②
Type							
Area, sq ft							
Span, ft							
M.A.C.	Length, ft						
	Longitudinal location, ft						
	Vertical location, ft						
	Lateral location, ft						
Aspect ratio							
Tip chord length, ft							
Root chord length, ft							
Root chord location	Longitudinal, ft						
	Vertical, ft						
Taper ratio							
Airfoil section ①	Root						
	Tip						
Leading-edge radius							
Sweepback of quarter-chord line, deg							
Dihedral angle, deg							
Incidence angle, deg							
Geometric twist, deg							
Loading, lb/ft^2							
Tail length							

Ⓑ Control surfaces

ITEM			Surface: Elevator	Aileron	Nose flap	Trailing-edge flap	Rudder	Speed brakes and spoilers	③
Type									
Area, sq ft									
Span, ft									
Location of ④	Longitudinal hinge ℄, ft								
	Lateral	Inboard edge, ft							
		Outboard edge, ft							
	Chord	Inboard edge, ft							
		Outboard edge, ft							
Sweepback of hinge ℄, deg									
Distance from hinge ℄ to centroid of area, ft									
Type and amount of aerodynamic balance									
Deflection range, deg or height/chord									
Airfoil section									
Trailing-edge thickness ratio									

Ⓒ Fuselage

Length, ft		
Width, ft		
Depth, ft		
Frontal area, sq ft		
Fineness ratio	Overall	
	Forebody	
	Afterbody	
Side area, sq ft		

Volume, cu ft		
Base area, sq ft		
Cavity area, sq ft		
Effective nose cone angle deg		
Duct areas	Inlet, sq ft	
	Comp. face, sq ft	
	Exit, sq ft	
Mass-flow ratio	Model	
	Prototype	

Ⓓ External stores

Length, ft		
Frontal area, sq ft		
Fineness ratio		
C.g. location from store nose	Longitudinal, ft	
	Vertical, ft	
Incidence, deg		

Ⓔ Tunnel balance

Pitch beam center ⑤		
Location	Longitudinal, ft	
	Lateral, ft	
	Vertical, ft	
	Percent, M.A.C.	
Yaw beam center		
Location	Longitudinal, ft	
	Lateral, ft	
	Vertical, ft	
	Percent, M.A.C.	

Notes:
① Give orientation
② Other types of all-movable surfaces
③ Slots, slats, etc.
④ For rudder inboard equals lower, etc.
⑤ Balance center to be as close as possible to prototype c.g.

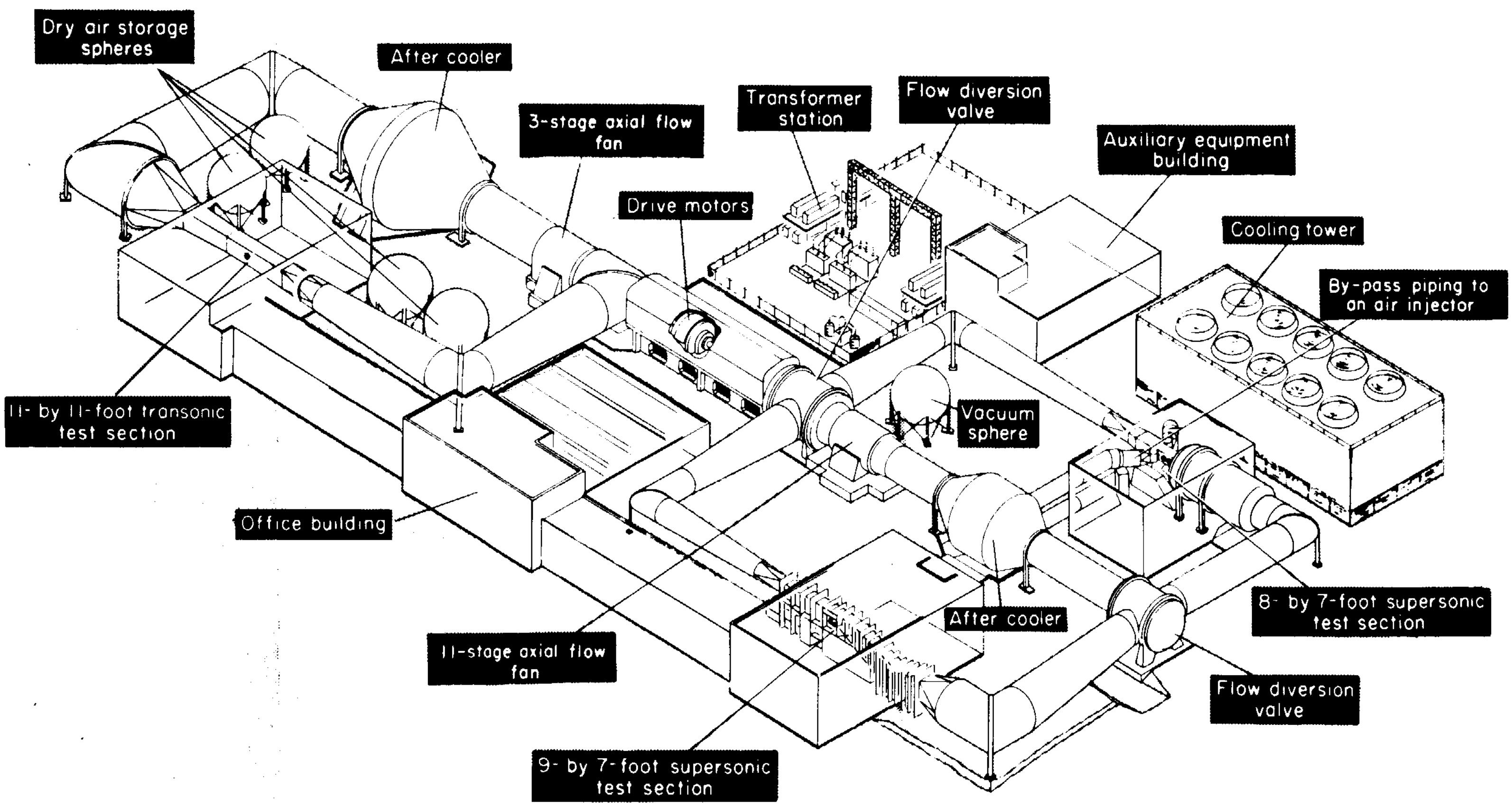


Figure 1. - Major components of the Ames Unitary Plan Wind Tunnel.

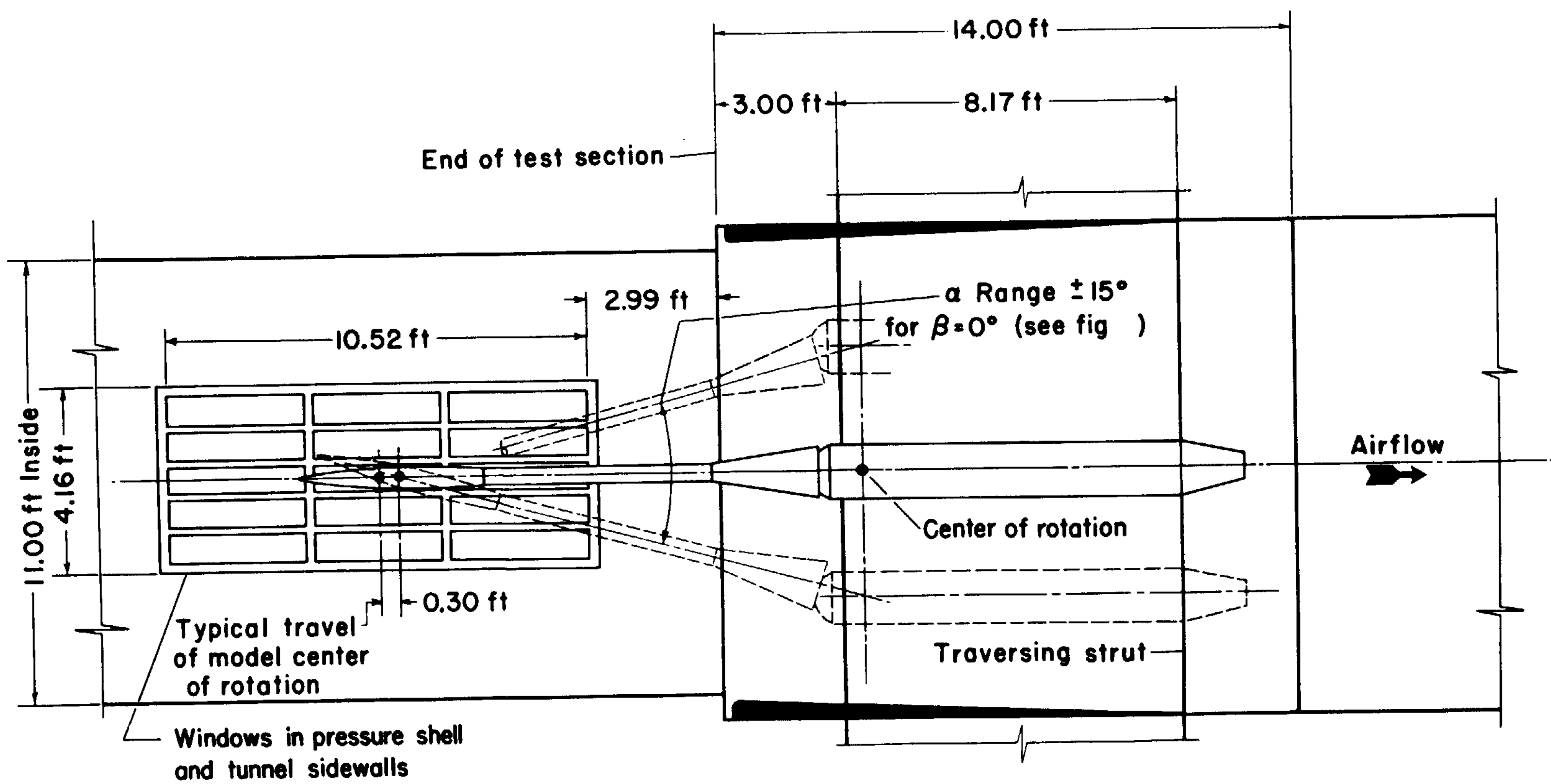


Figure 2. - Test section and model support details; 11- by 11-foot transonic test section, Ames Unitary Plan Wind Tunnel.

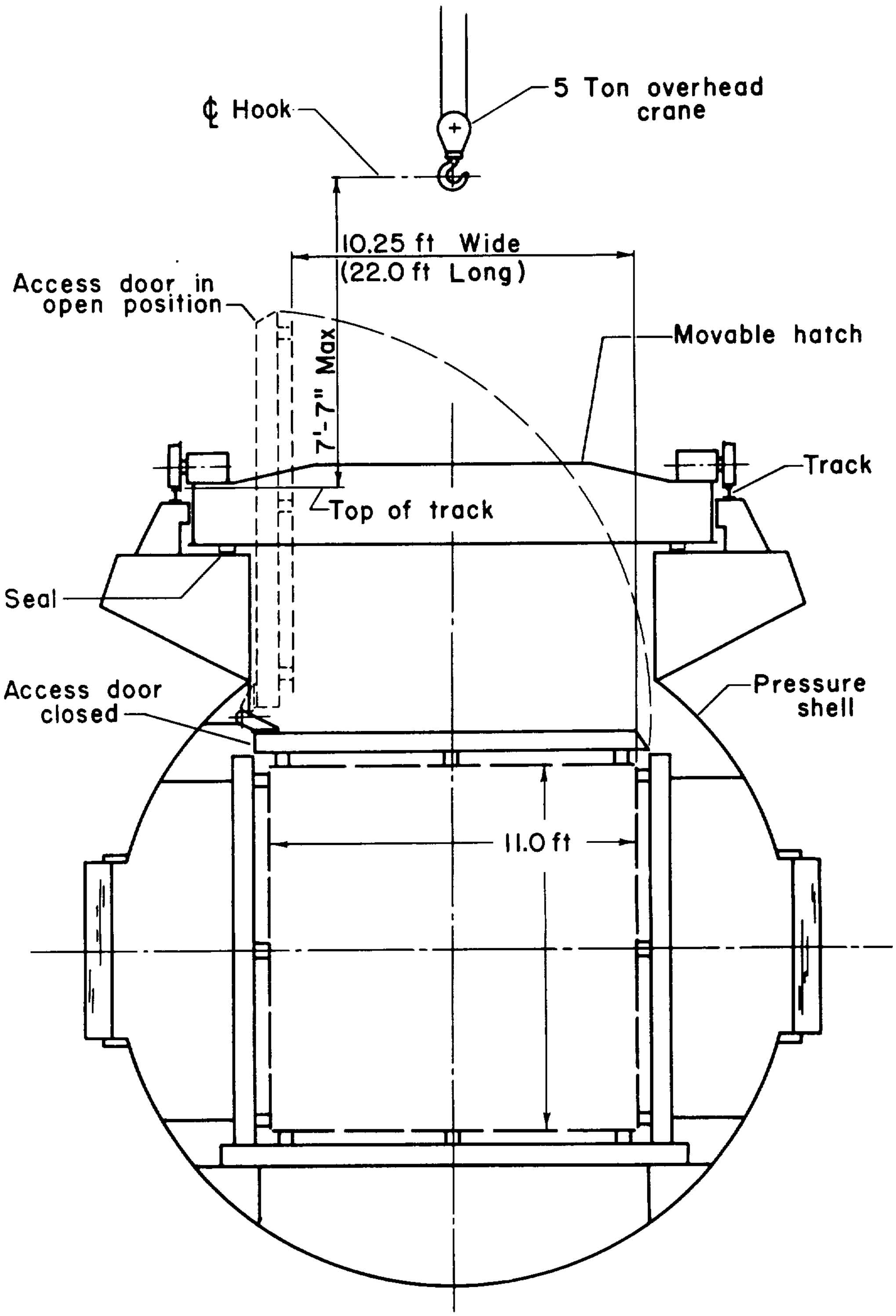


Figure 3. - Access hatch dimensions; 11- by 11-foot transonic test section, Ames Unitary Plan Wind Tunnel.

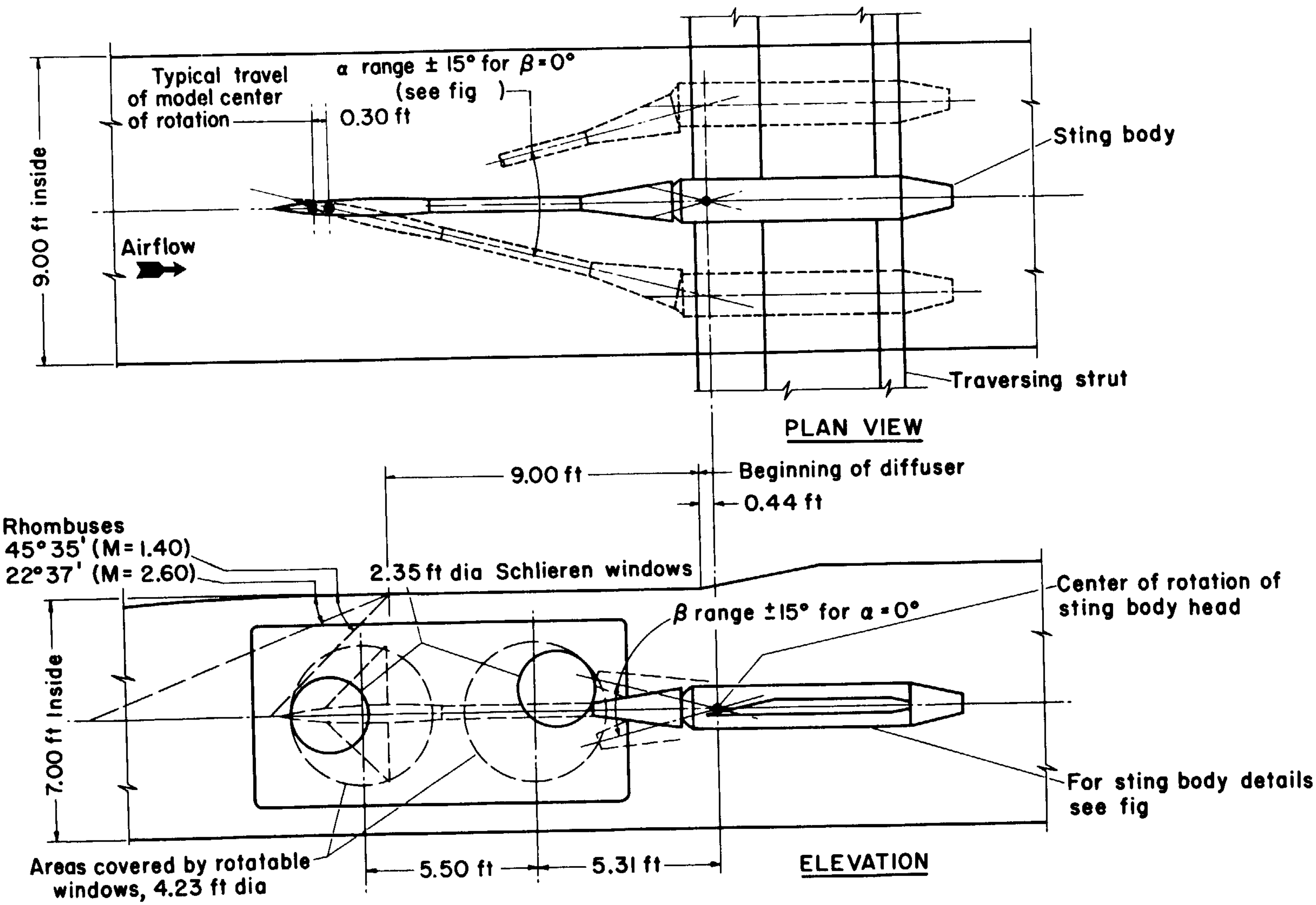


Figure 4. - Test section and model support details; 9- by 7-foot supersonic test section, Ames Unitary Plan Wind Tunnel.

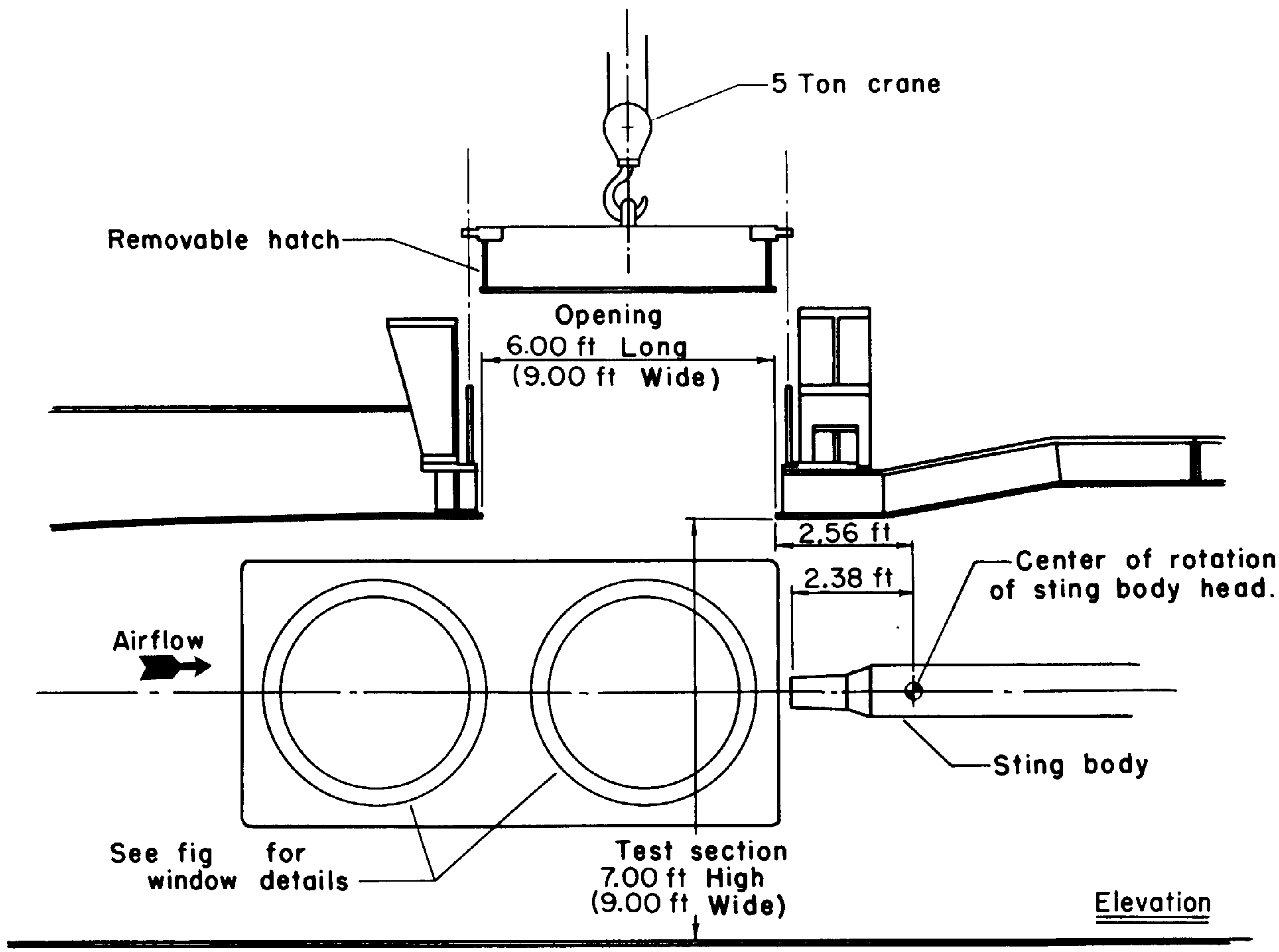


Figure 5. - Access hatch dimensions; 9- by 7-foot supersonic test section, Ames Unitary Plan Wind Tunnel.

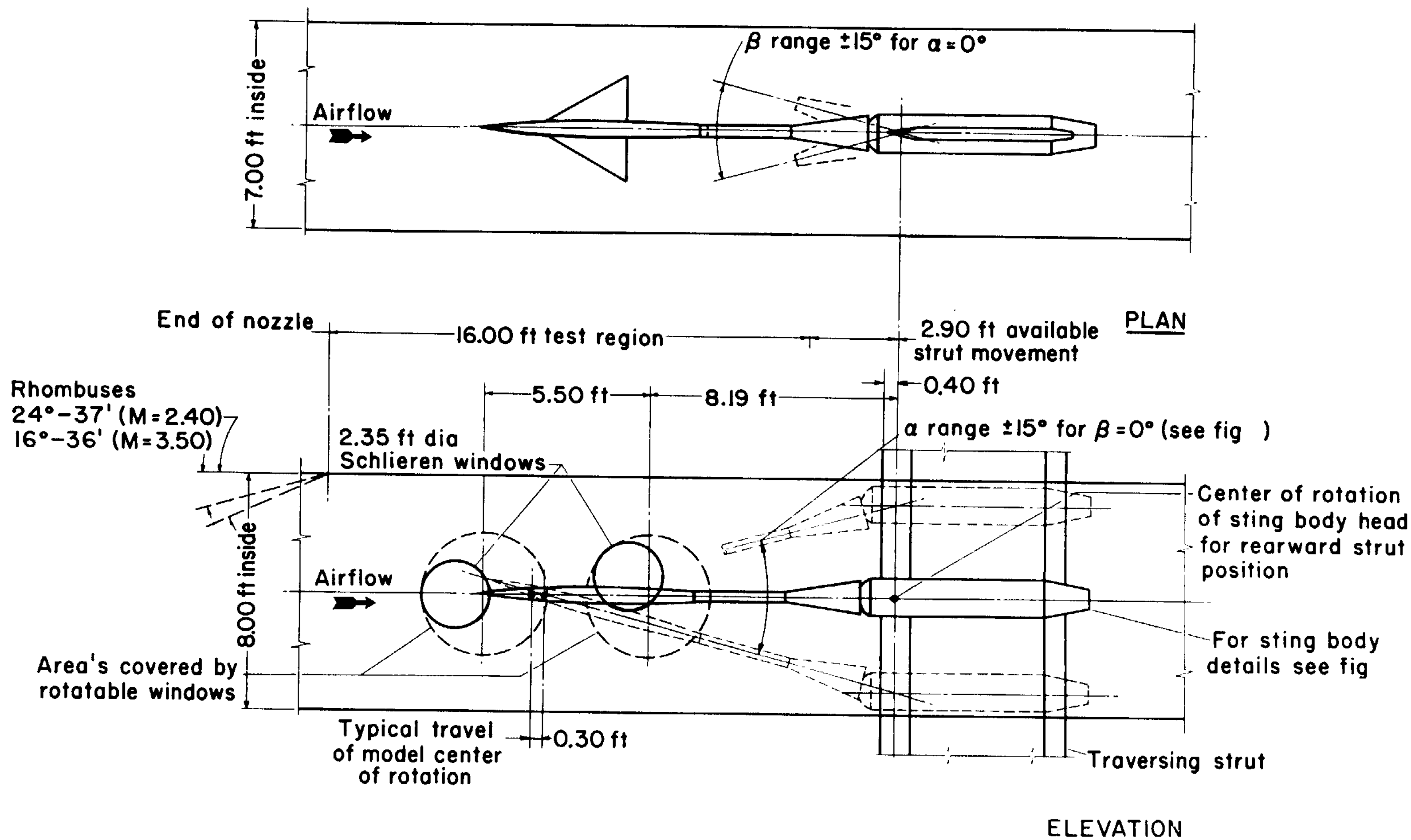


Figure 6. - Test section and model support details; 8- by 7-foot supersonic test section, Ames Unitary Plan Wind Tunnel.

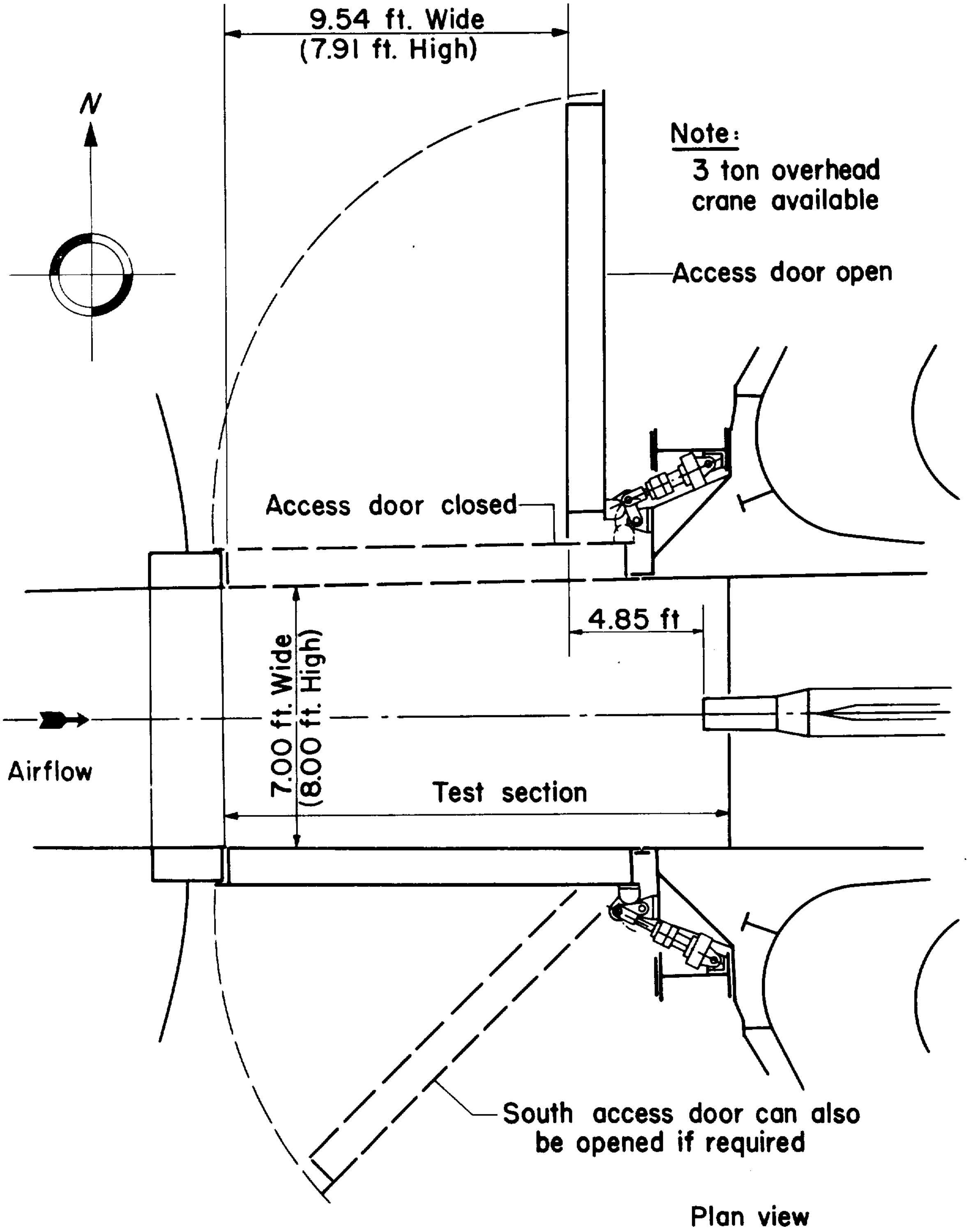


Figure 7. - Access hatch dimensions; 8- by 7-foot supersonic test section, Ames Unitary Plan Wind Tunnel.

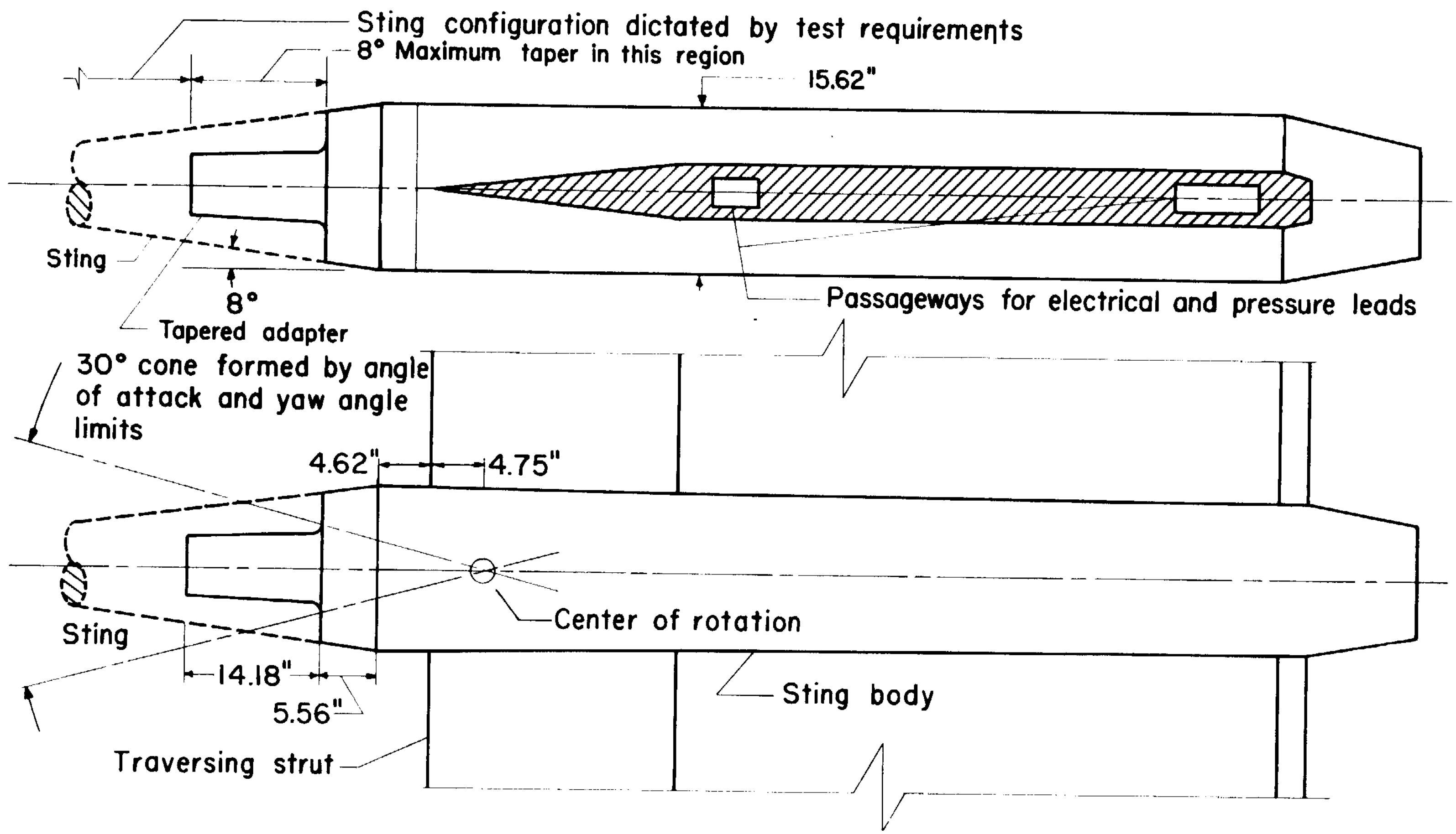


Figure 8. - General arrangement of the cross strut and central body to which the model support sting is attached, Ames Unitary Plan Wind Tunnel.

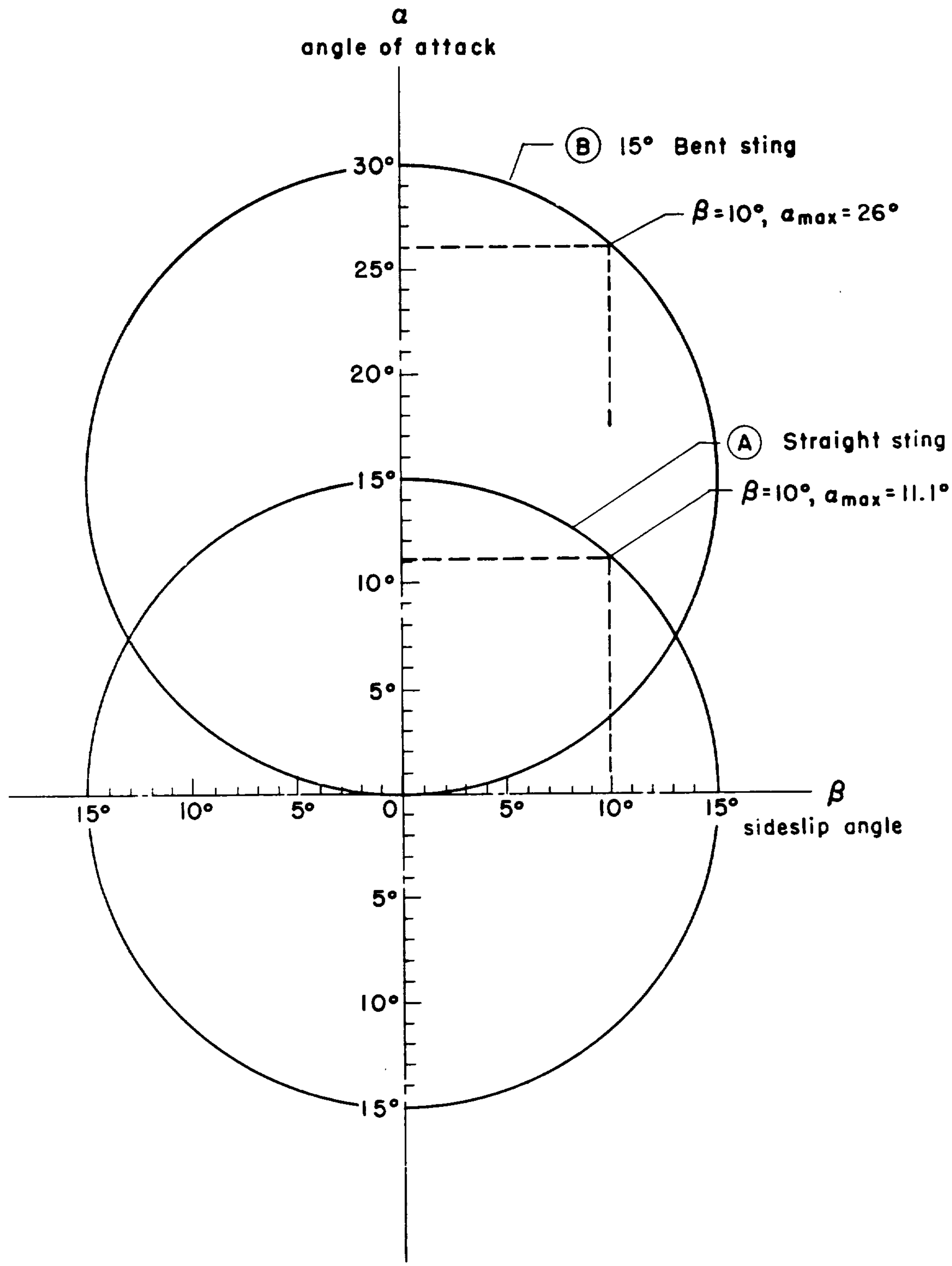


Figure 9. - Angle-of-attack and angle-of-sideslip ranges, Ames Unitary Plan Wind Tunnel.

1 Strain-gage leads
2 Strain-gage dial indication
3 Tabulation of strain-gage readings and data from supplementary servos
4 Pressure tubes, or wires from supplementary pick-ups
5 Six channels of electrical signals from transmitting selsyns
6 Ten channels of digitized data
7 Tabulated strain-gage data
8 Neon lights indicating values of digitized data from assembly unit digitizer
9 Factor board
10 Electric typewriter recording factor board entries
11 Digitized data from 10 channel recorder, assembly unit digitizer (supplementary servo results), and factor board
12 Digitized data from 6 channel recorder and factor board
13 Tape punch. Tape contains aerodynamic coefficients plus scale factors and zero offsets necessary for plotting.
14 Tape reader to convert tape punches to electrical signals used to actuate plotter
15 Aerodynamic coefficients plus scale factors and zero offsets
16 Tabulated aerodynamic coefficients
17 Digitized aerodynamic coefficients
18 Aerodynamic coefficients recorded in punched paper tape

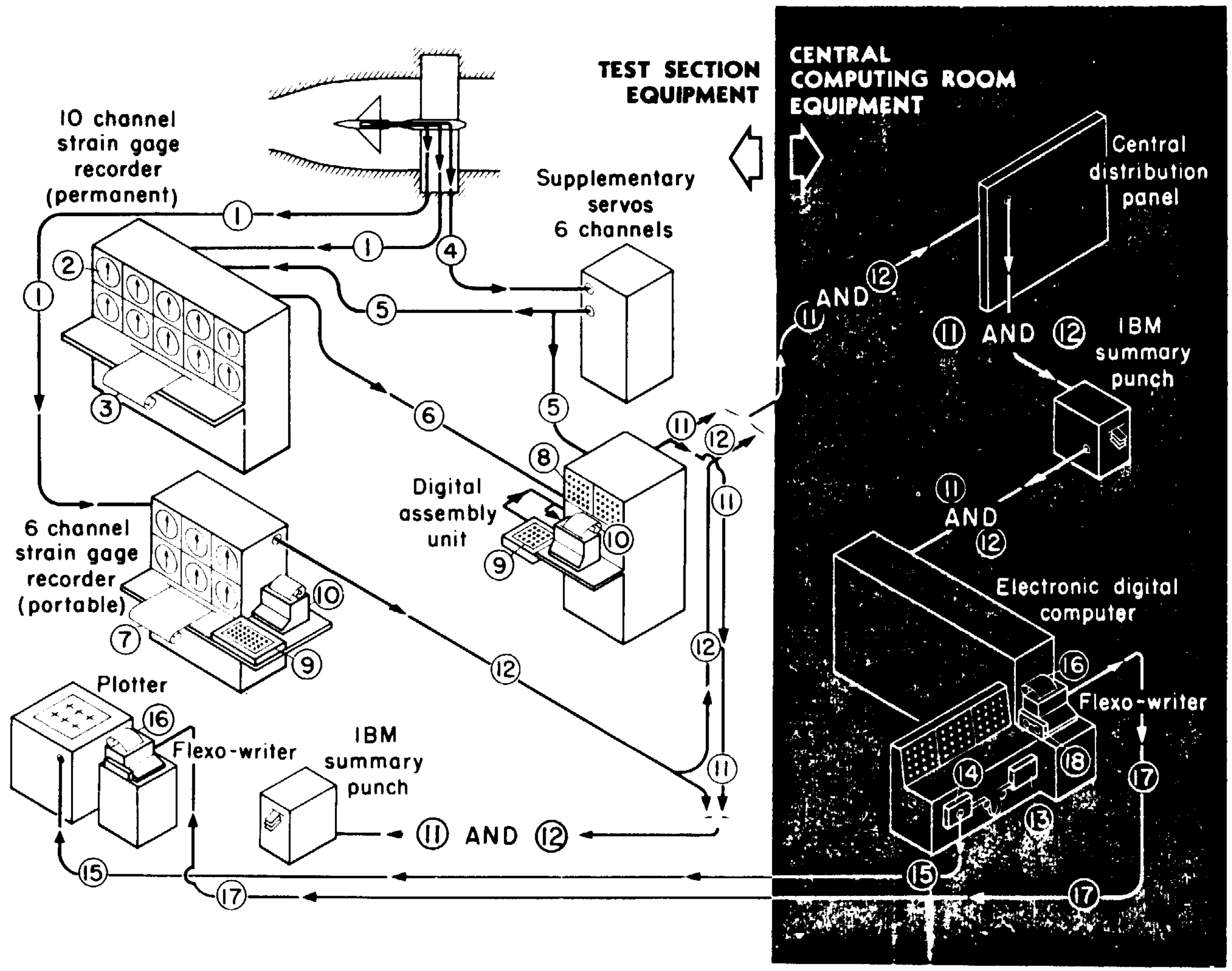


Figure 10. - Schematic of data processing system for the Ames Unitary Plan Wind Tunnel.

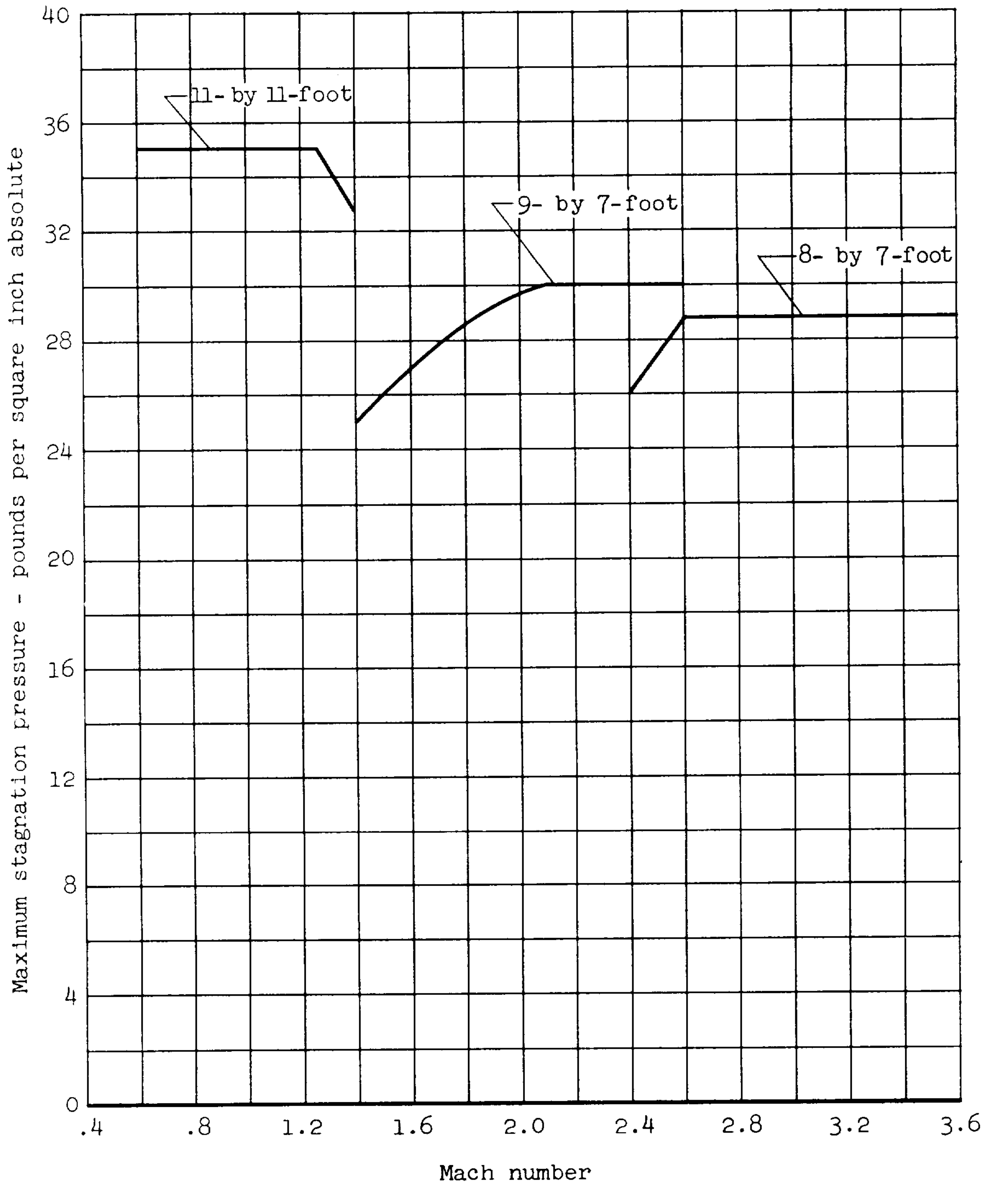


Figure 11. - Maximum operable stagnation pressure for the three circuits of the Ames Unitary Plan Wind Tunnel.

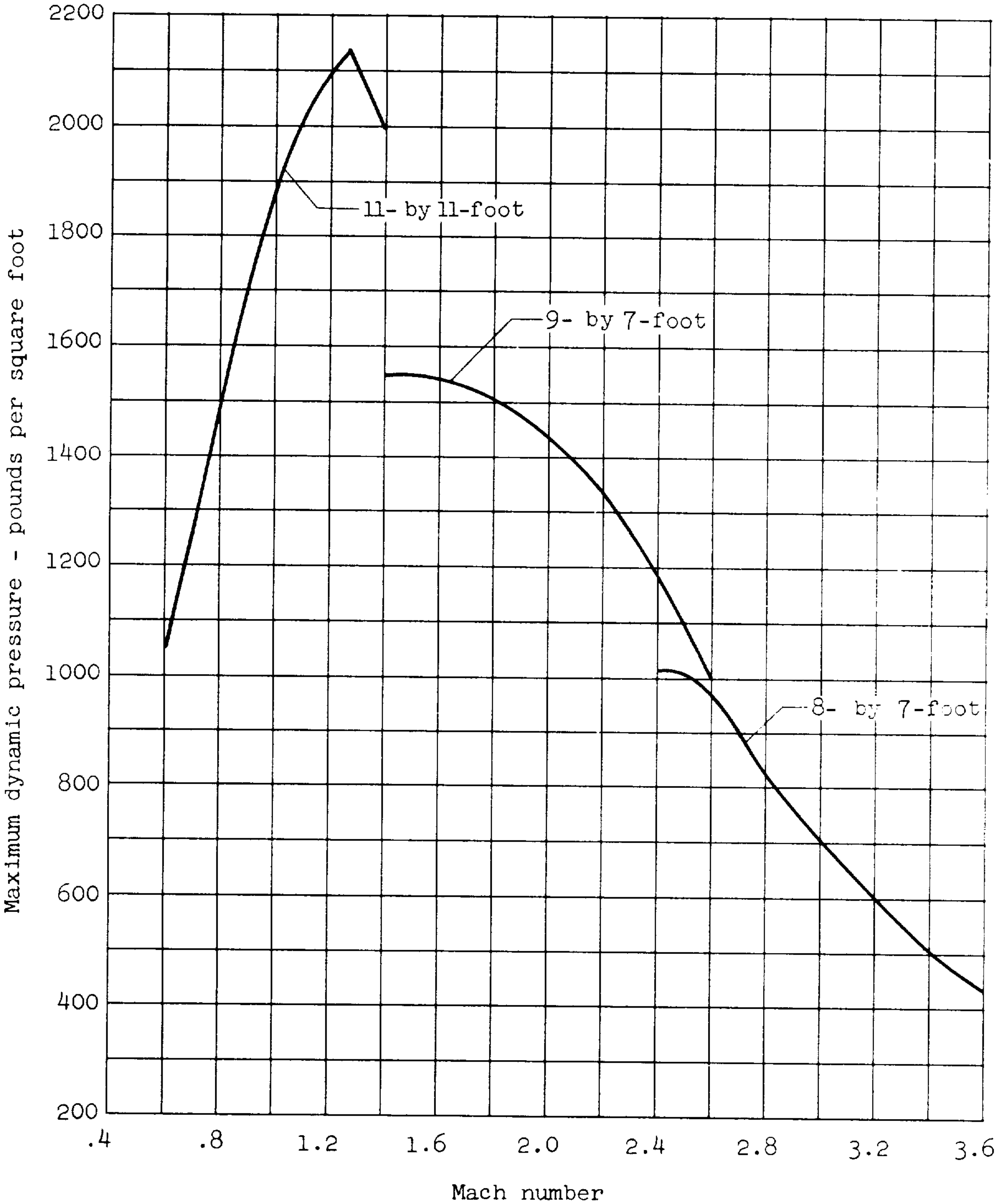


Figure 12. - Maximum operable test section dynamic pressure for the three circuits of the Ames Unitary Plan Wind Tunnel.

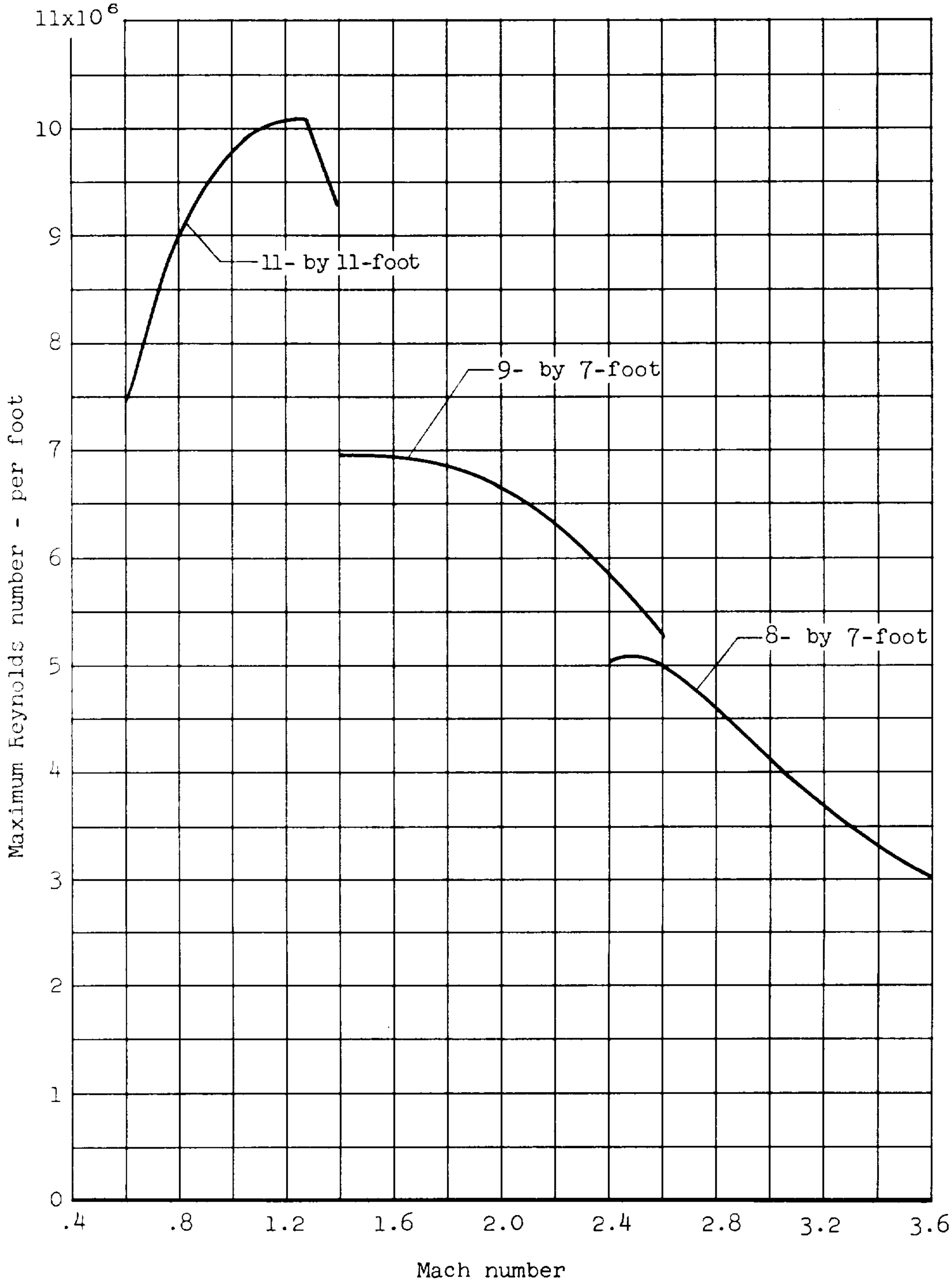


Figure 13. - Maximum operable test section Reynolds number for the three circuits of the Ames Unitary Plan Wind Tunnel.

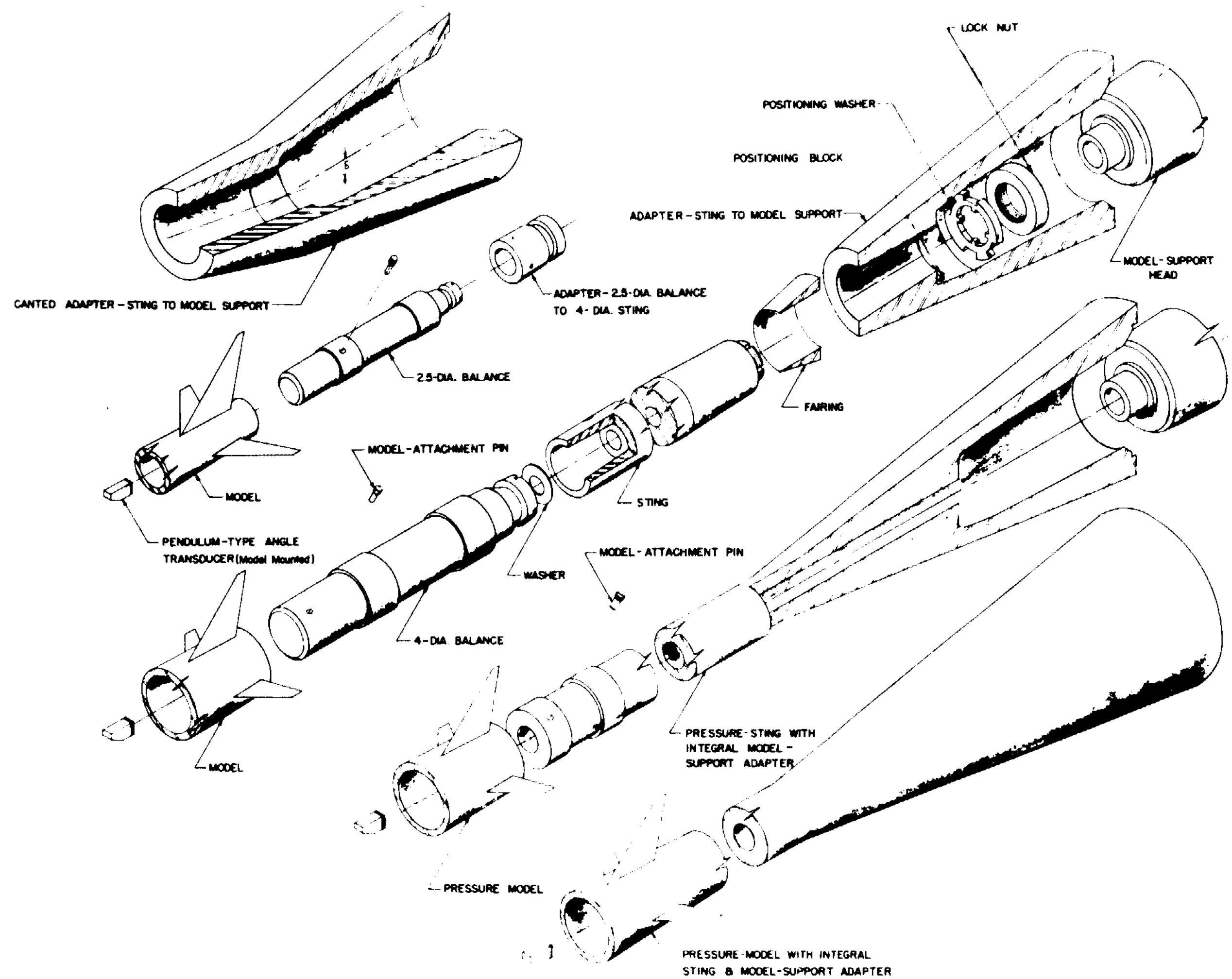
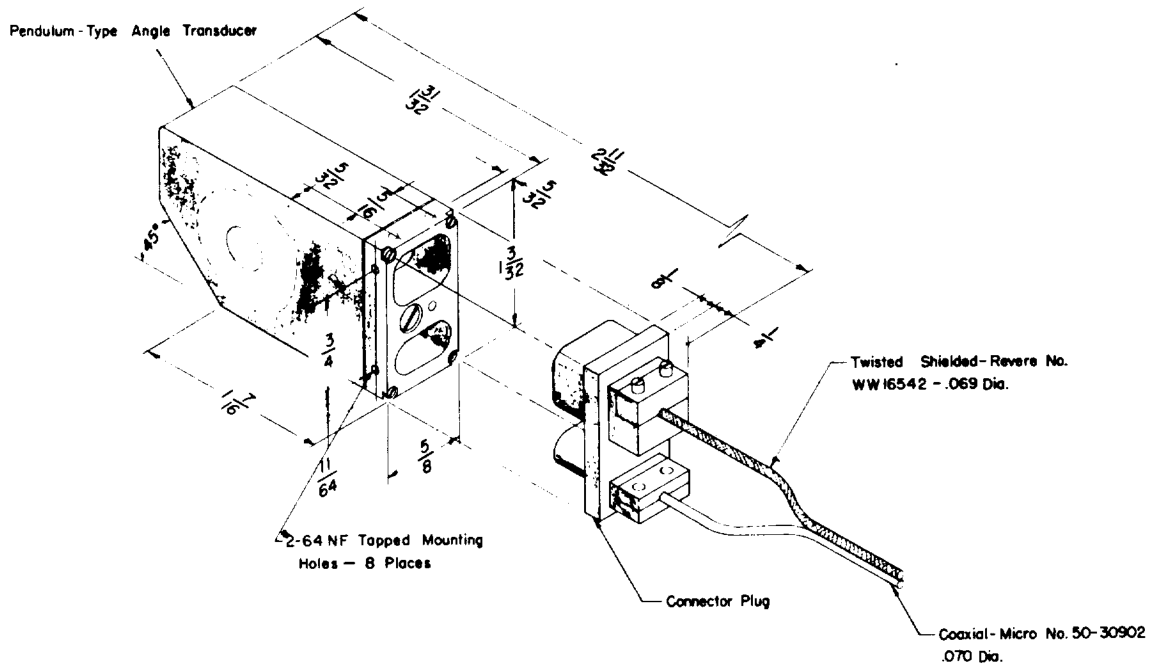
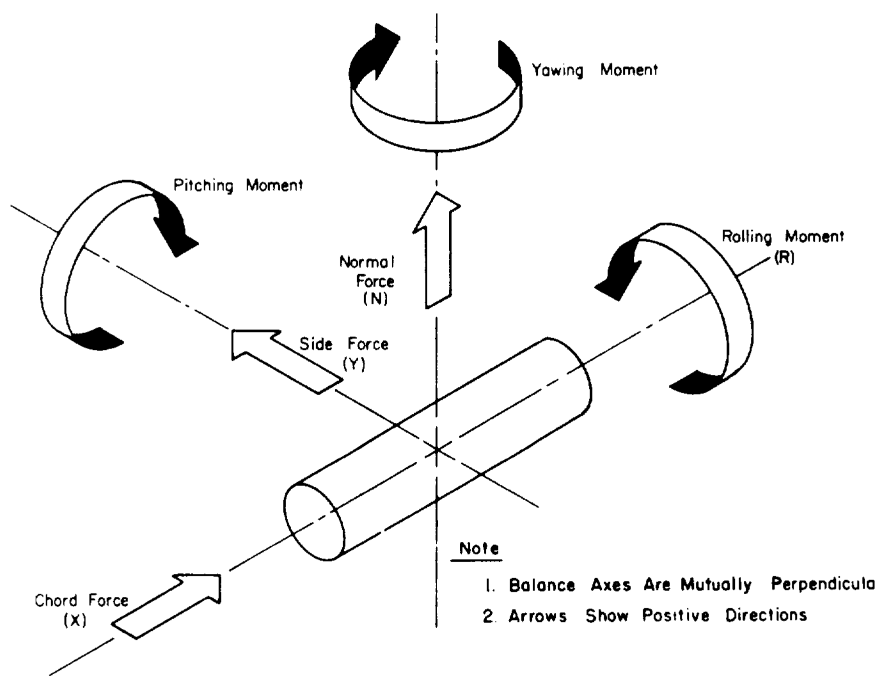


Figure 14. - General arrangements for sting mounting force models and pressure-distribution models in the Ames Unitary Plan Wind Tunnel.

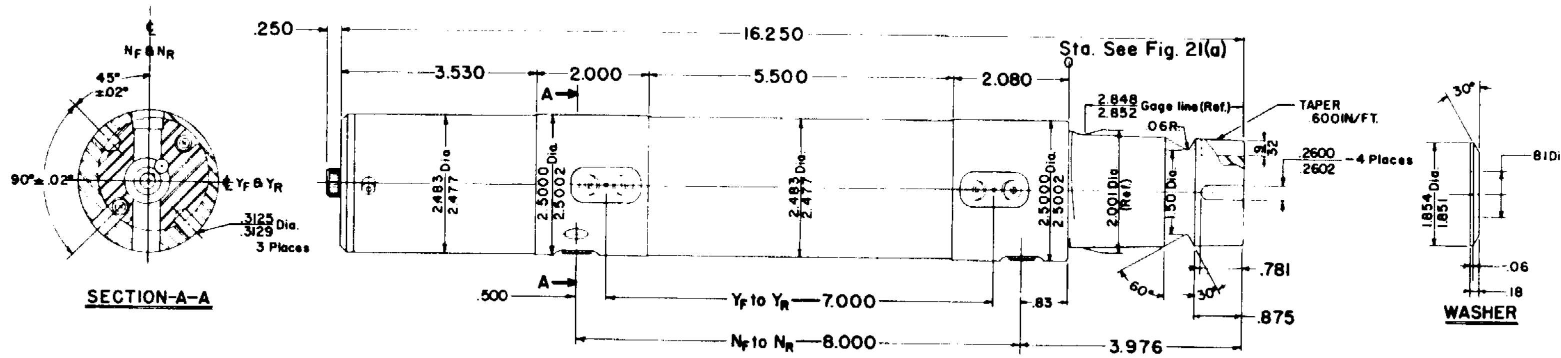


(a) Pendulum-type angle transducer and connector plug.



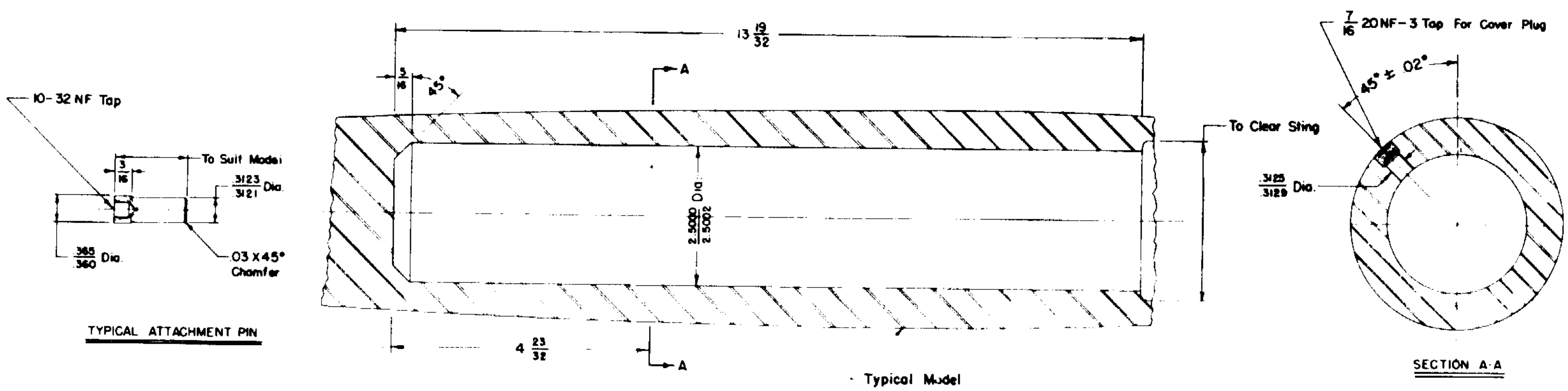
(b) Diagram of forces and moments on six-component internal strain-gage balance.

Figure 15. - Transducer and forces and moments, Ames Unitary Plan Wind Tunnel.



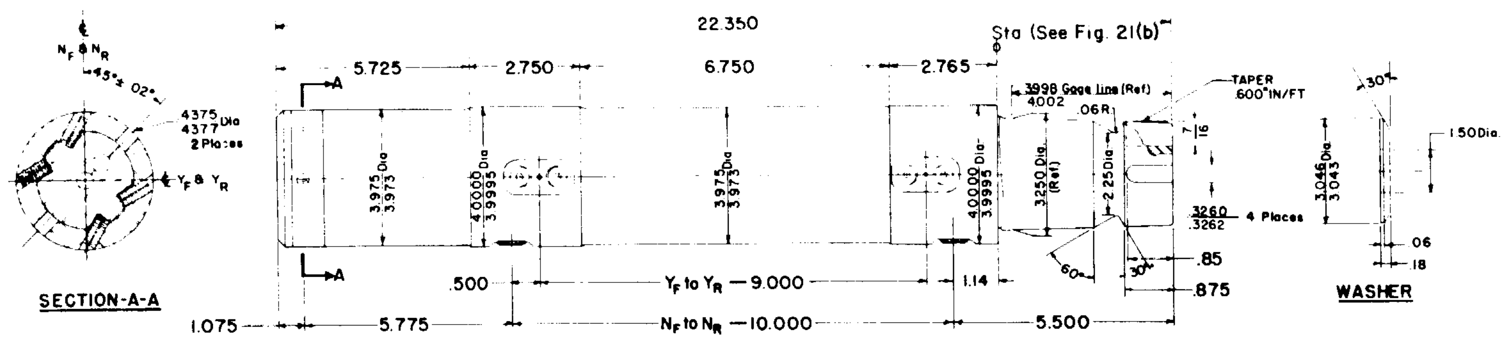
COMPONENT	CAPACITY
NORMAL FORCE – Front – (N_F)	± 1400 lbs.
NORMAL FORCE – Rear – (N_R)	± 1400 lbs.
SIDE FORCE – Front – (Y_F)	± 700 lbs.
SIDE FORCE – Rear – (Y_R)	± 700 lbs.
CHORD FORCE – (X)	± 280 lbs.
ROLLING MOMENT – (R)	± 2000 in-lbs.

(a) SS-2.5 inch diameter six-component internal strain-gage balance.



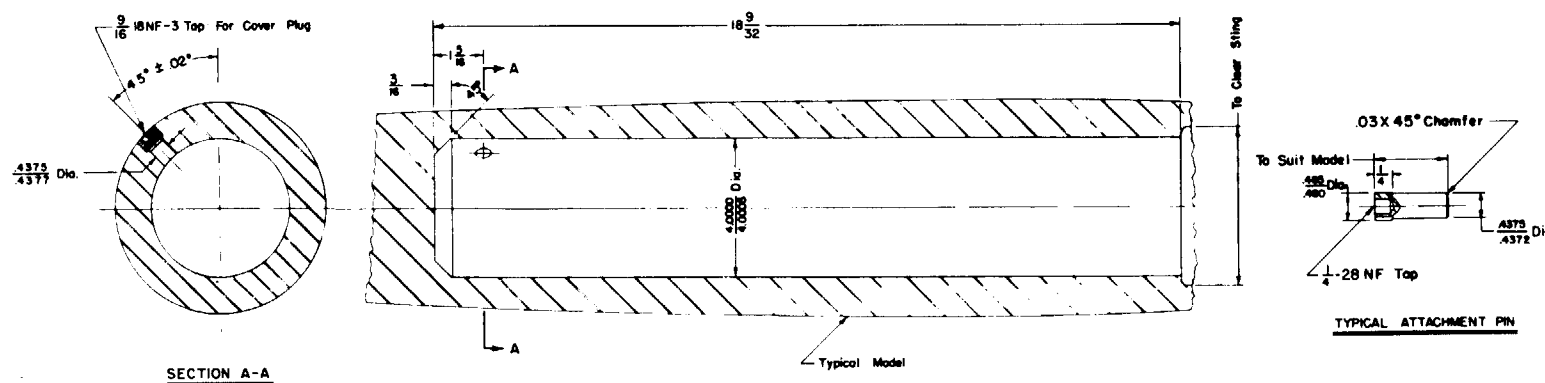
(b) Socket in model - SS-2.5 inch diameter six-component internal strain-gage balance.

Figure 16. - Six-component internal strain-gage balances, Ames Unitary Plan Wind Tunnel.



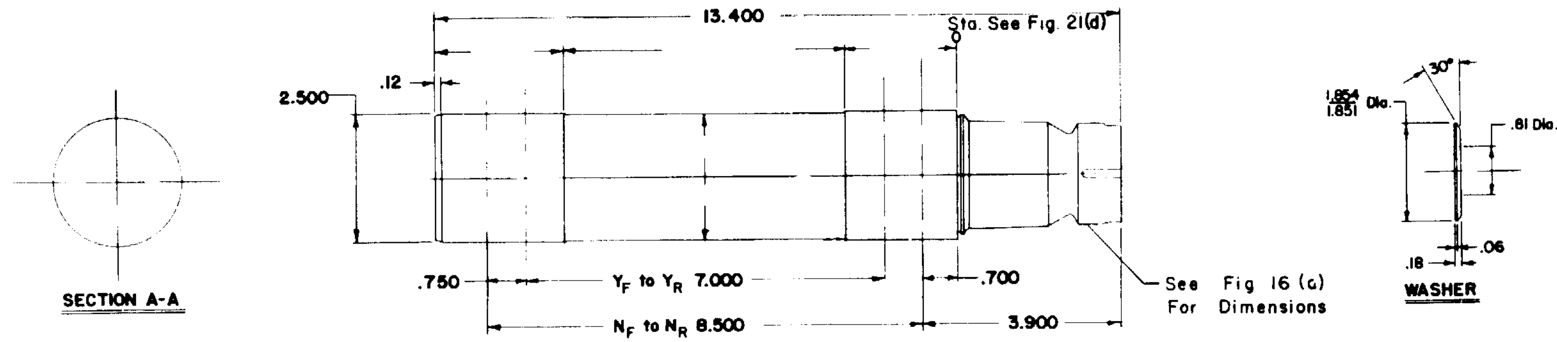
COMPONENT	CAPACITY
NORMAL FORCE - Front - (N_F)	± 4000 lbs.
NORMAL FORCE - Rear - (N_R)	± 4000 lbs.
SIDE FORCE - Front - (Y_F)	± 2000 lbs.
SIDE FORCE - Rear - (Y_R)	± 2000 lbs.
CHORD FORCE — (X)	± 1000 lbs.
ROLLING MOMENT - (R)	± 10,000 in.-lbs.

(c) SS-4 inch diameter six-component internal strain-gage balance.



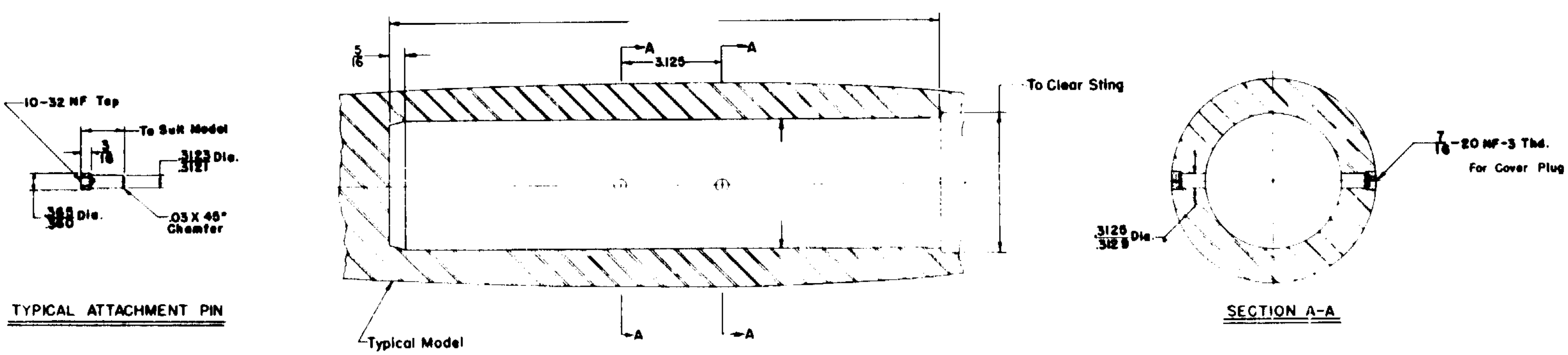
(d) Socket in model - SS-4 inch diameter six-component internal strain-gage balance.

Figure 16. - Continued.



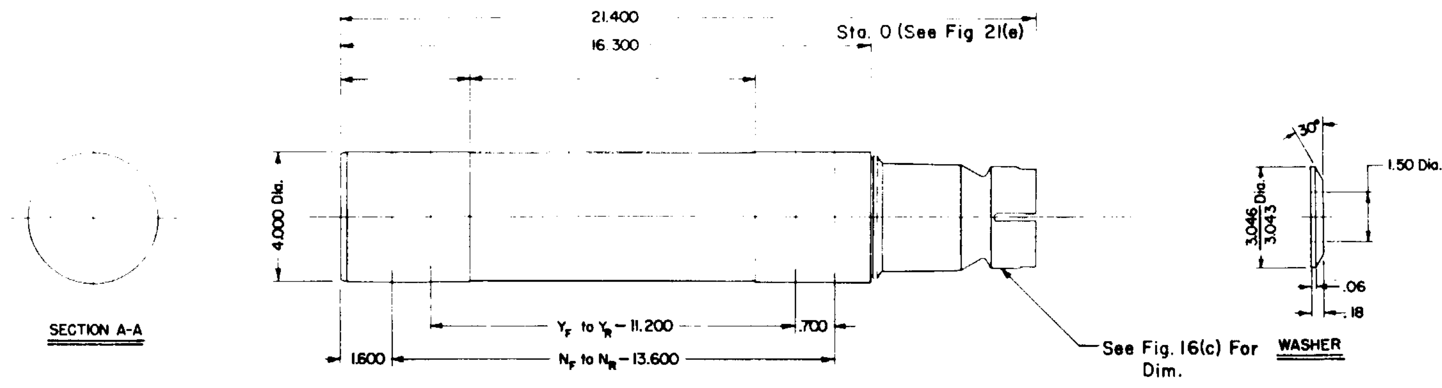
COMPONENT	CAPACITY
NORMAL FORCE - Front -(N_F)	± 1400 lbs.
NORMAL FORCE - Rear -(N_R)	± 1400 lbs.
SIDE FORCE - Front -(Y_F)	± 700 lbs.
SIDE FORCE - Rear -(Y_R)	± 700 lbs.
CHORD FORCE -(X)	± 200 lbs.
ROLLING MOMENT (R)	± 2000 in.lbs.

(e) T-2.5 inch diameter six-component internal strain-gage balance.



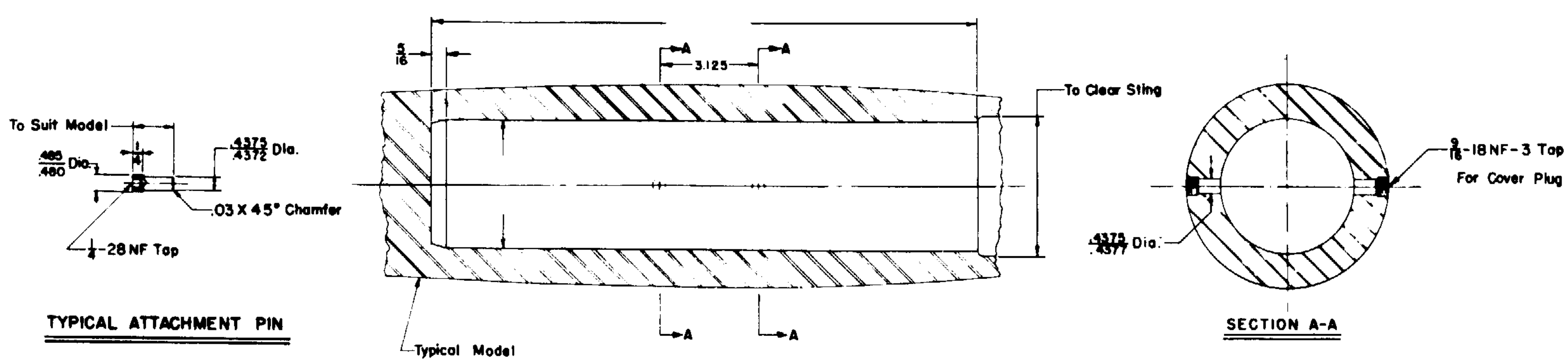
(f) Socket in model - T-2.5 inch diameter six-component internal strain-gage balance.

Figure 16. - Continued.



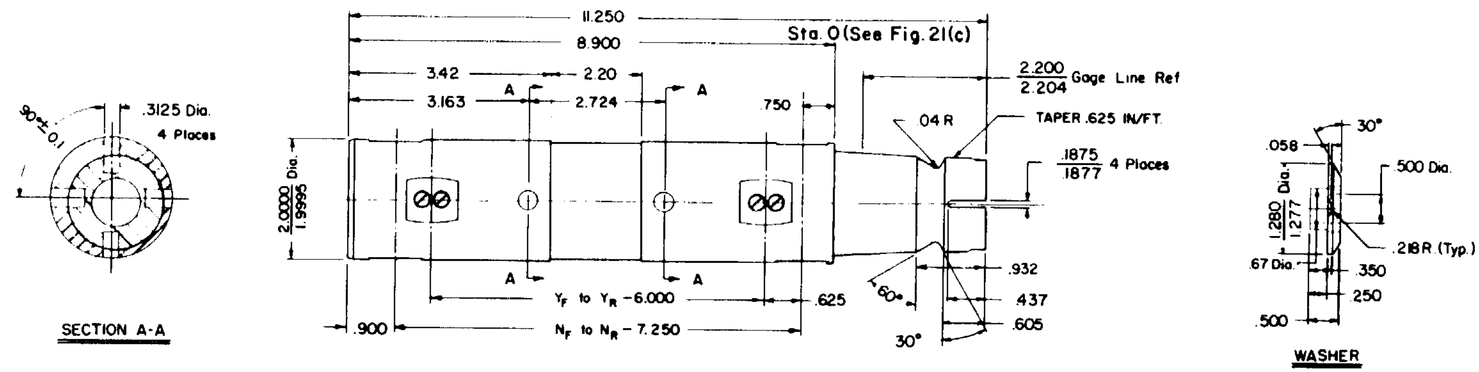
COMPONENT	CAPACITY
NORMAL FORCE – Front – (N_F)	4000 lbs.
NORMAL FORCE – Rear – (N_R)	4000 lbs.
SIDE FORCE – Front – (Y_F)	2000 lbs.
SIDE FORCE – Rear – (Y_R)	2000 lbs.
CHORD FORCE – (X)	1000 lbs.
ROLLING MOMENT – (R)	10,000 in.-lbs.

(g) T-4 inch diameter six-component internal strain-gage balance.



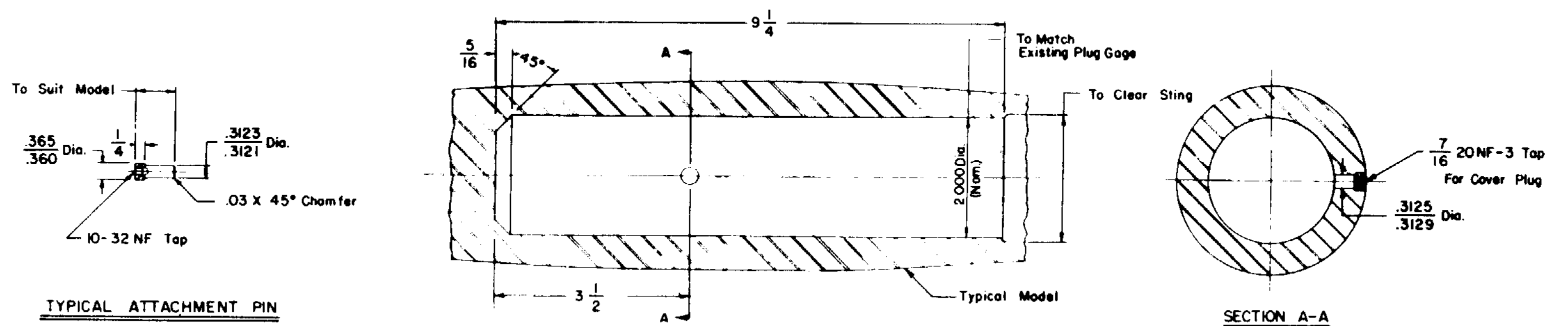
(h) Socket in model - T-4 inch diameter six-component internal strain-gage balance.

Figure 16. - Continued.



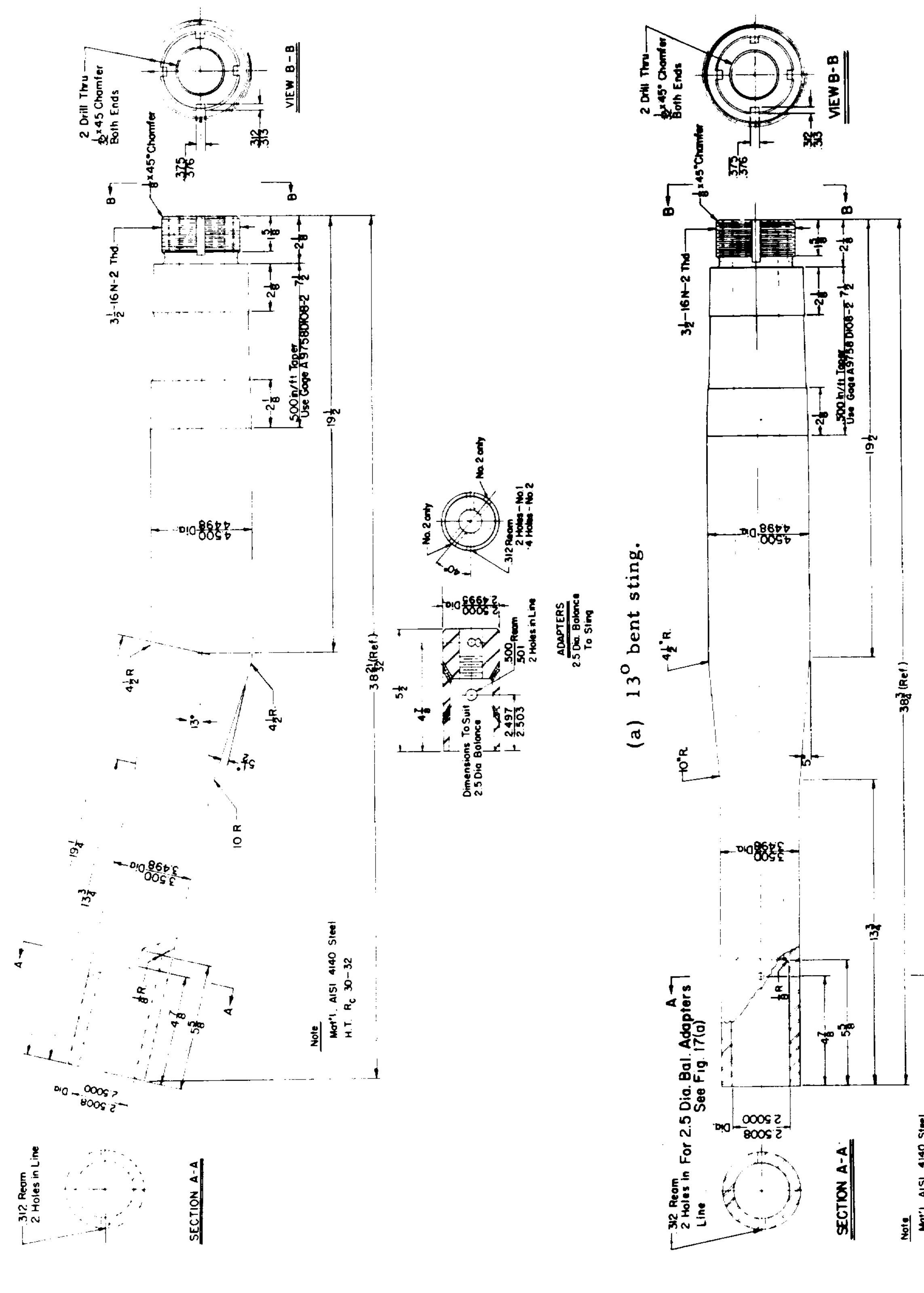
COMPONENT	CAPACITY
Normal Force - Front (N_F)	± 900 lbs
Normal Force - Rear (N_R)	± 900 lbs.
Side Force - Front - (Y_F)	± 450 lbs.
Side Force - Rear - (Y_R)	± 450 lbs.
Chord Force - (X)	± 160 lbs.
Rolling Moment - (R)	± 1,000 in-lbs

(i) T-2 inch diameter six-component internal strain-gage balance.



(j) Socket in model - T-2 inch diameter six-component internal strain-gage balance.

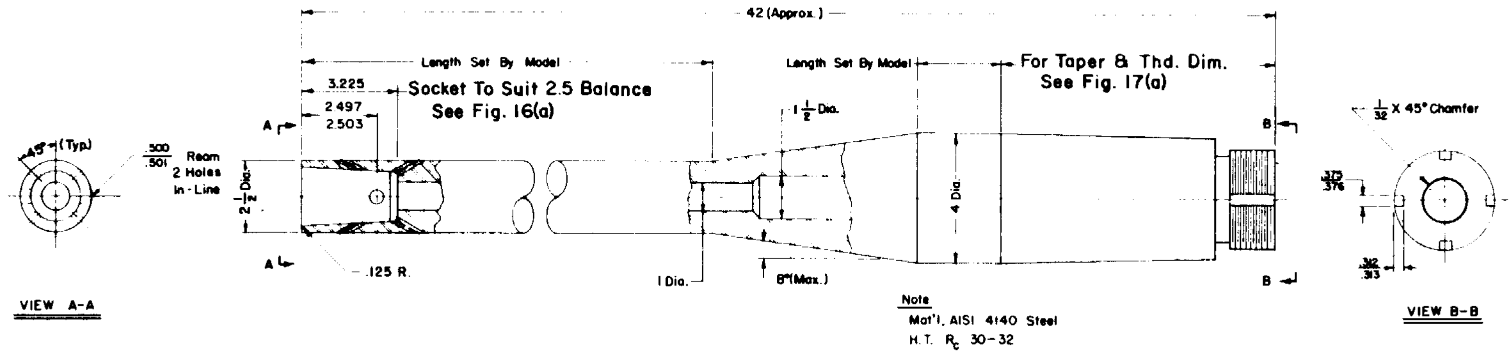
Figure 16. - Concluded.



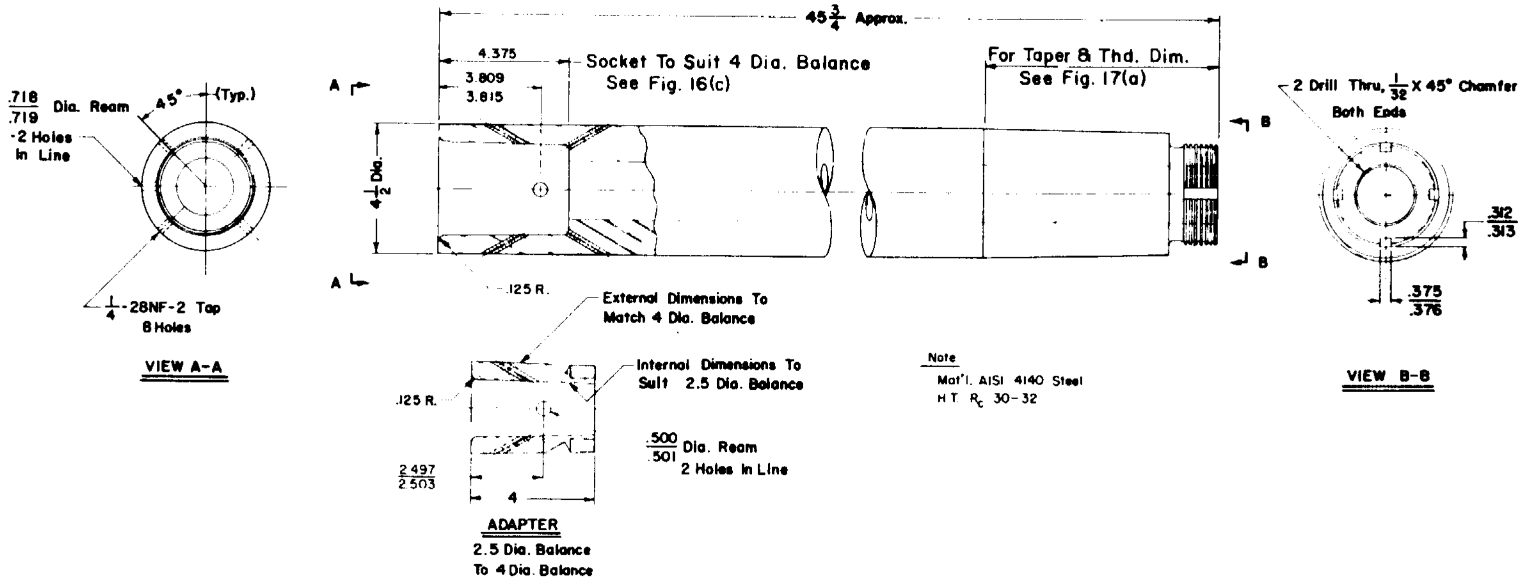
(a) 13° bent sting.

(b) Straight sting.

Figure 17. - 3-1/2 inch diameter stings, Ames Unitary Plan Wind Tunnel.



(a) Straight sting - 2-1/2 inch diameter.



(b) Straight sting - 4-1/2 inch diameter.

Figure 18. - Proposed stings, Ames Unitary Plan Wind Tunnel.

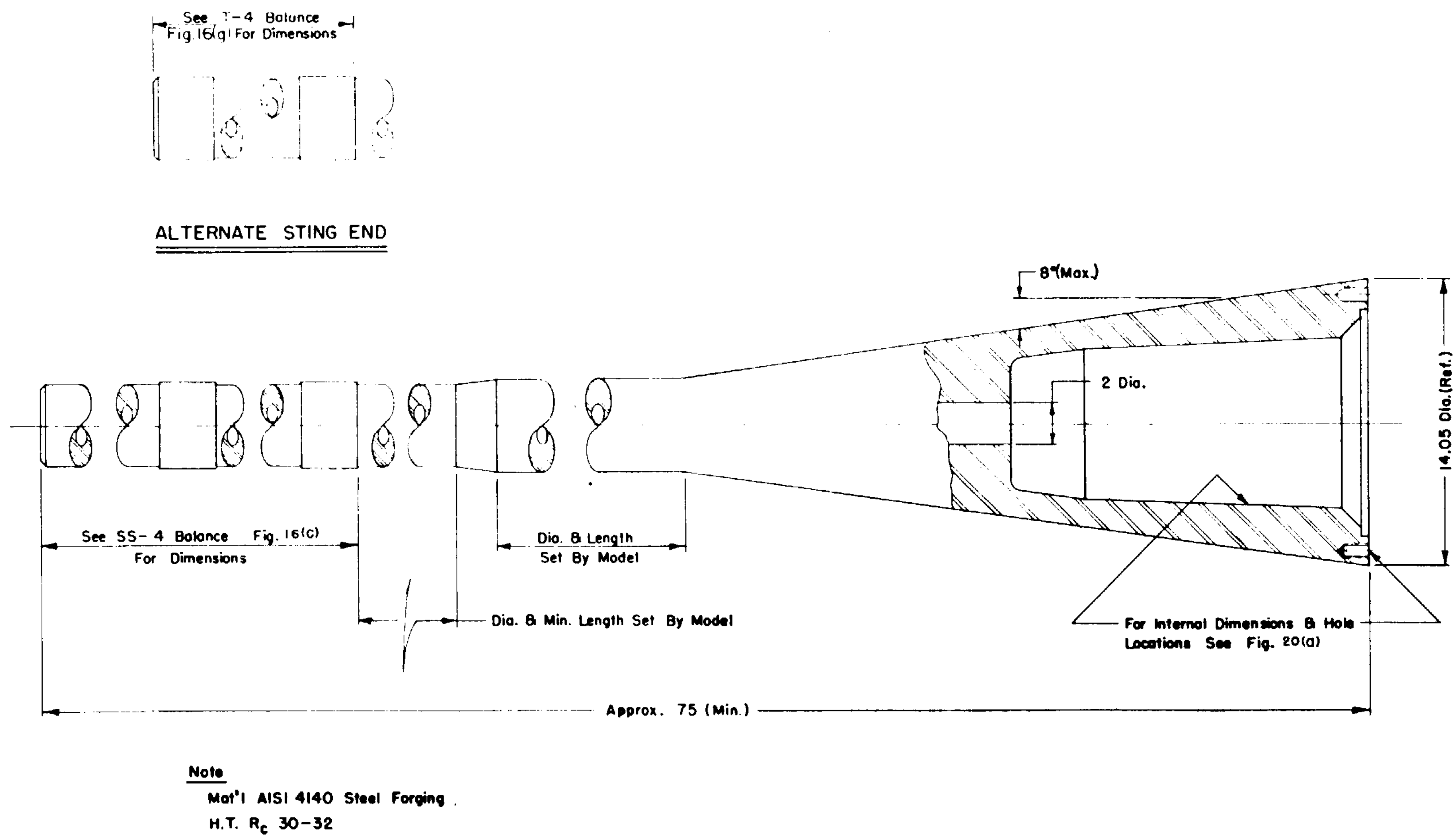
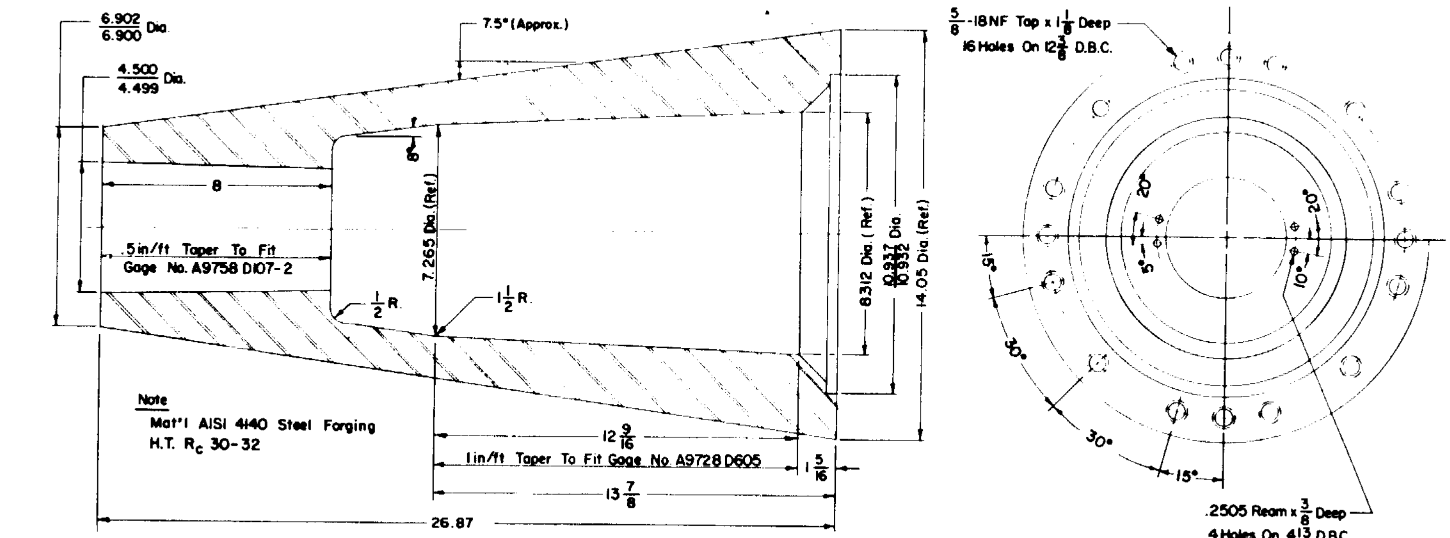
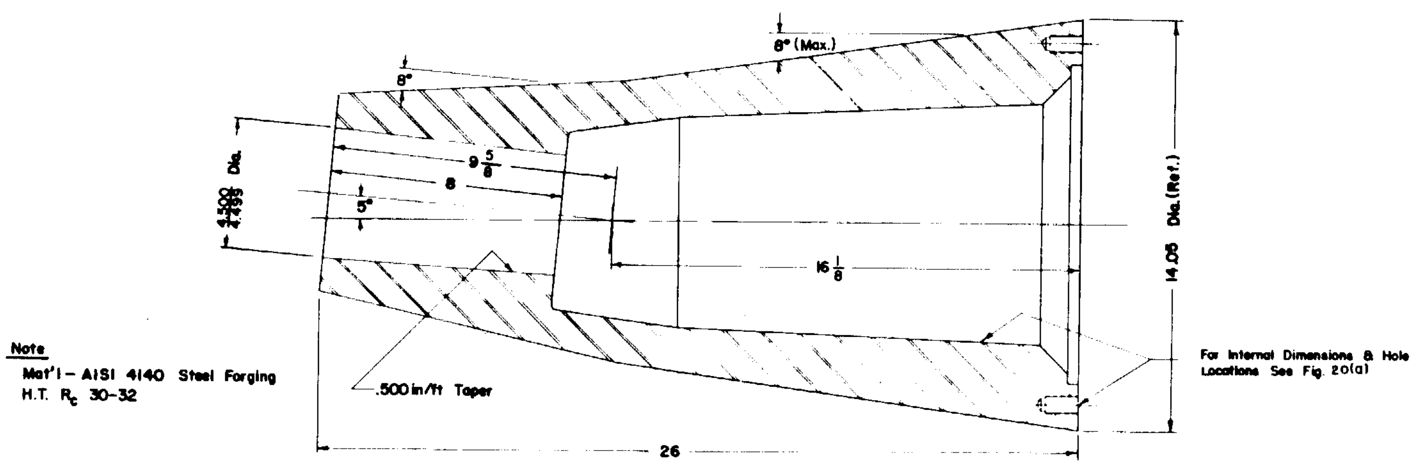


Figure 19.- Proposed pressure sting with integral adapter - sting to model support, Ames Unitary Plan Wind Tunnel.

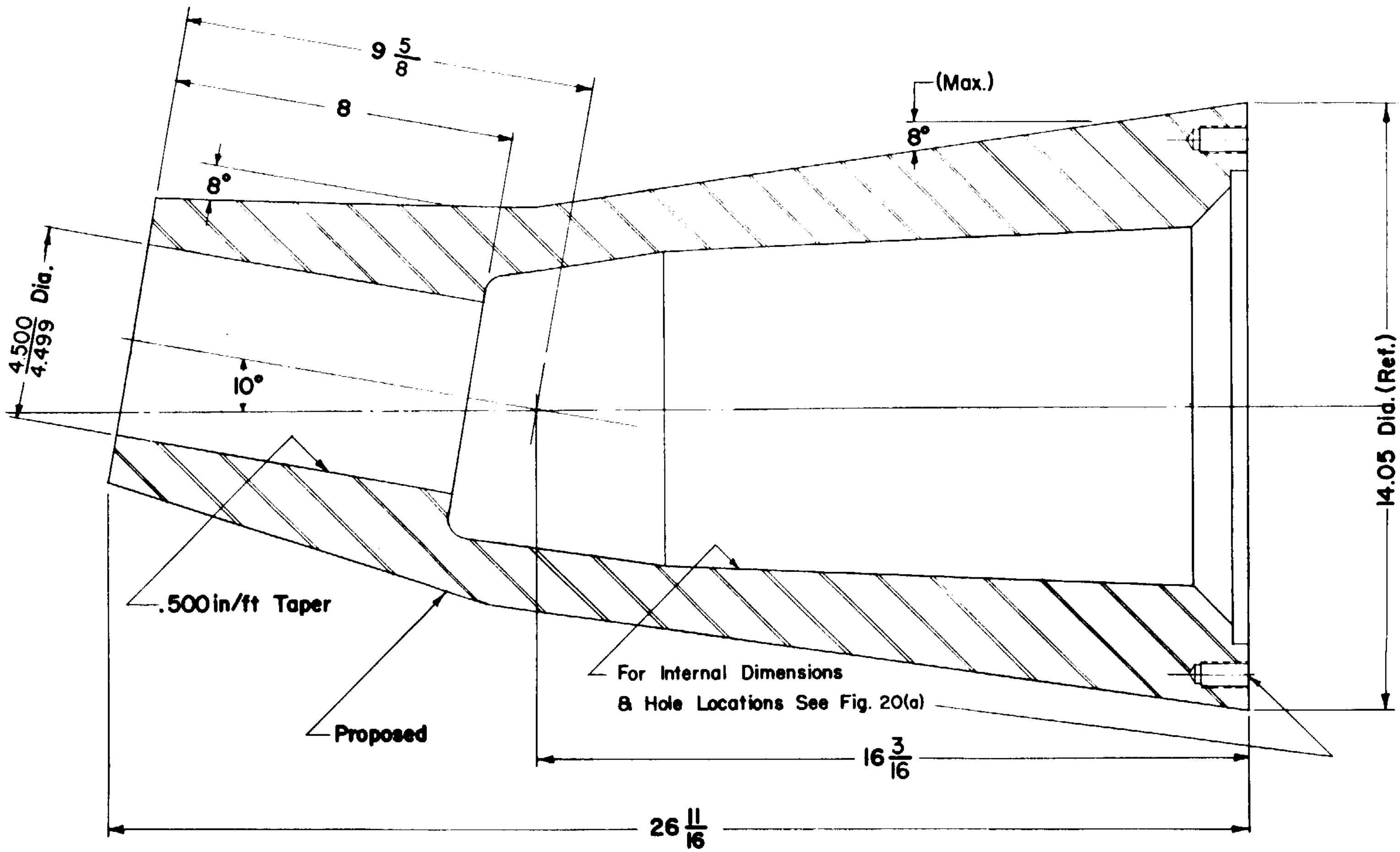


(a) Straight adapter.



(b) 5^{0} canted adapter (proposed).

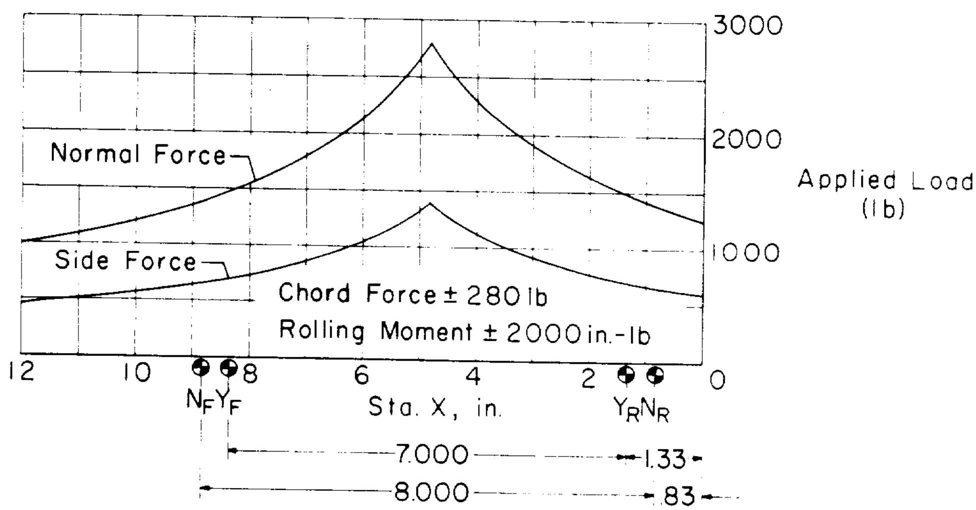
Figure 20. - Adapters - sting to model support, Ames Unitary Plan Wind Tunnel.



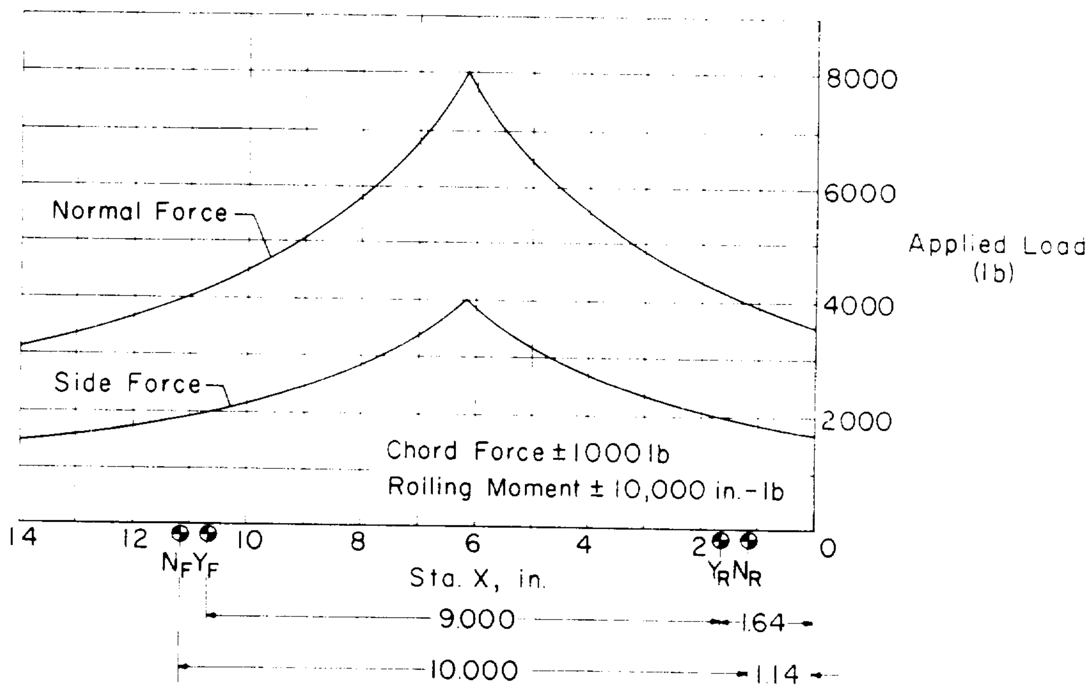
Note
Mat'l- AISI 4140 Steel Forging
H.T. R_c 30-32

(c) 10° canted adapter (proposed).

Figure 20. - Concluded.

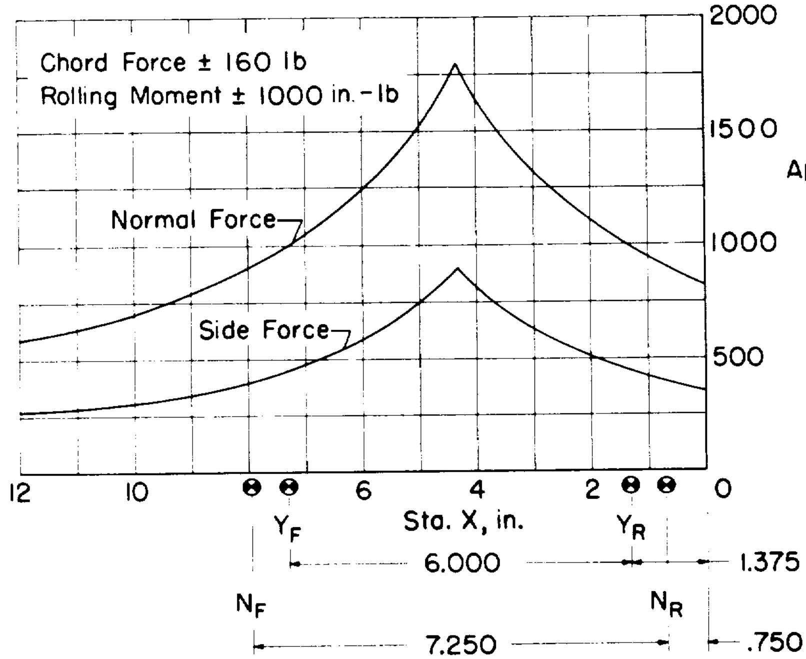


(a) SS-2.5 inch diameter six-component internal strain-gage balance.

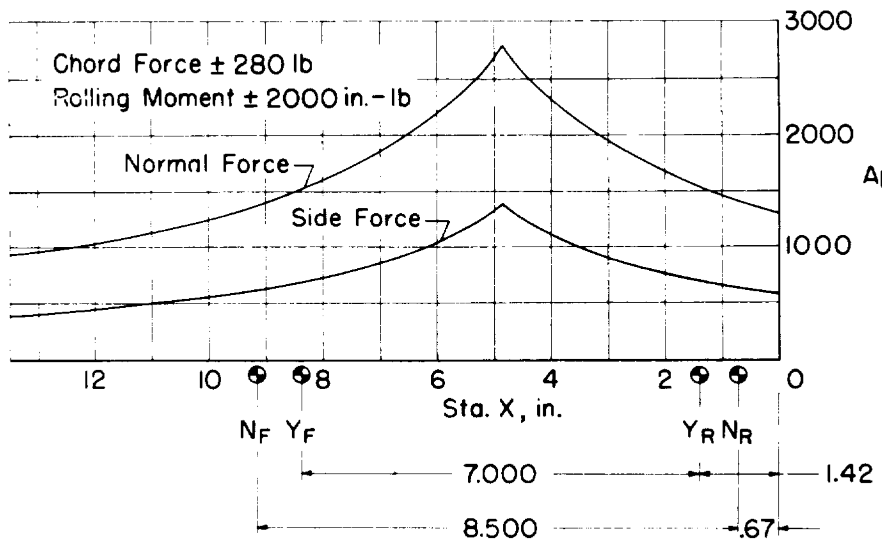


(b) SS-4 inch diameter six-component internal strain-gage balance.

Figure 21.- Load limits of six-component internal strain-gage balances, Ames Unitary Plan Wind Tunnel.

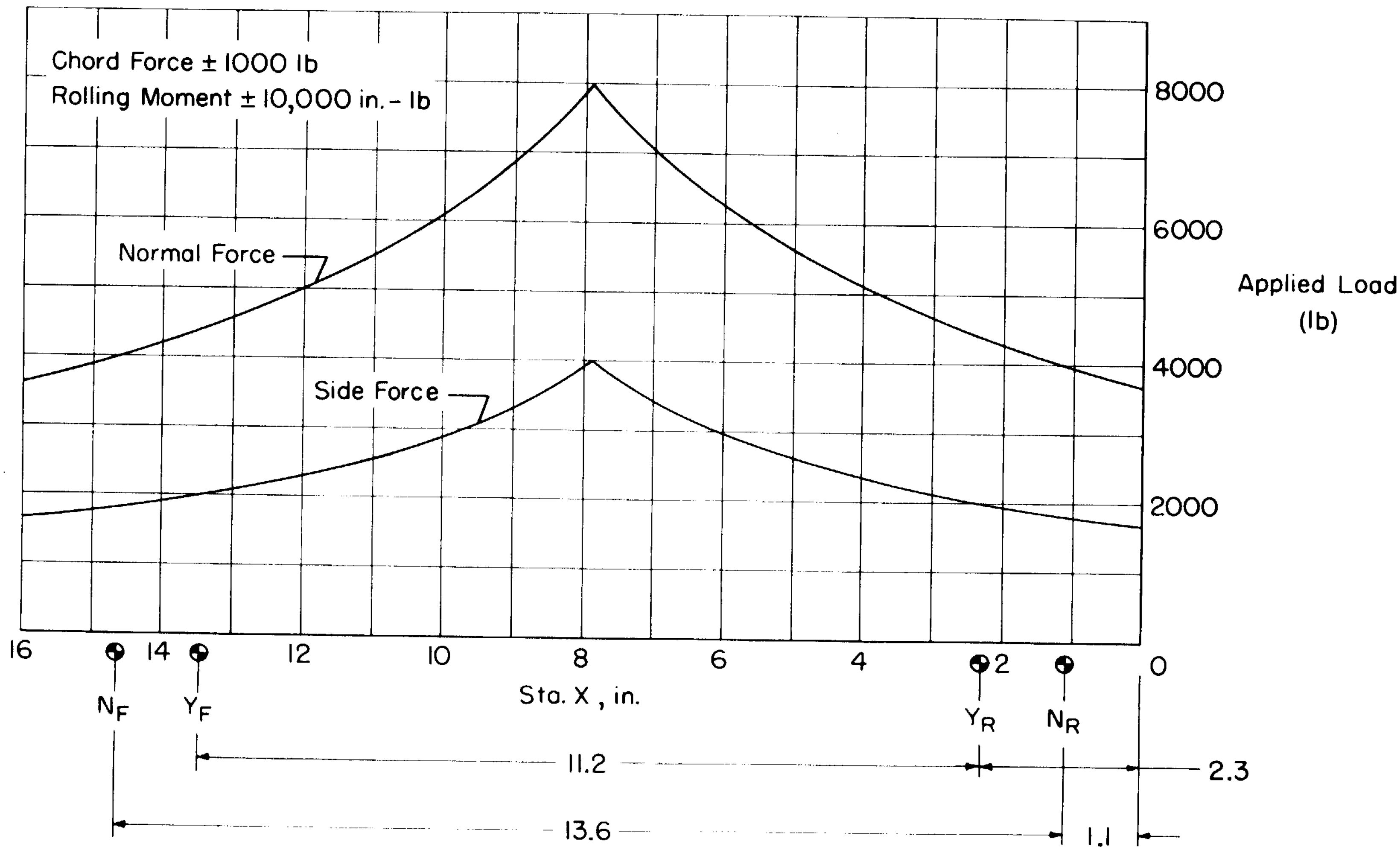


(c) T-2 inch diameter six-component internal strain-gage balance.



(d) T-2.5 inch diameter six-component internal strain-gage balance.

Figure 21.- Continued.



(e) T-4 inch diameter six-component internal strain-gage balance.

Figure 21. - Concluded.

THE LEWIS UNITARY PLAN WIND TUNNEL

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NACA

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THE LEWIS UNITARY PLAN WIND TUNNEL

GENERAL DESCRIPTION

A plan view of the Lewis Unitary Plan Wind Tunnel is shown in figure 1. The tunnel has a Mach number range of 2 to 3.5 and can be operated throughout the entire Mach number range on either an aerodynamic cycle at various air densities or on a propulsion cycle. On the aerodynamic cycle, the tunnel operates as a closed return-type tunnel, and on the propulsion cycle it operates as an open nonreturn-type tunnel. The main components are:

Air dryer building: The purpose of the air dryer building is to dry the air used in the tunnel. It contains 1900 tons of absorbent known as type I grade D activated alumina in six beds 3 feet thick. The dryer is designed to pass 1838 pounds of air per second entering at 85° F with a dewpoint of 67° F and leaving with a dewpoint of -40° F for a two-hour period. Reactivation of the activated alumina requires four hours heating and four hours cooling.

Valve 1: Valve 1 is a 15-foot-diameter butterfly valve, which is used to control the air flow from the air dryer building when the tunnel is operated on the propulsion cycle.

Valve 2: Valve 2 is a 4-foot-diameter butterfly valve, which is used as a shutoff valve for the bypass line around valve 1.

Valves 3 and 4: Valves 3 and 4 are 14-inch- and 4-foot-diameter butterfly valves, respectively. They are used to control the air flow from the air dryer building when the tunnel is operated on the aerodynamic cycle at low air densities.

Valve 5: Valve 5 is a $5\frac{1}{2}$-foot-diameter butterfly valve, used as an air-temperature control valve for the air entering compressor 2. It controls the air temperature by acting as a bypass for the air past cooler 2.

Cooler 2: Cooler 2 is a finned-tube, water-coil-type heat exchanger, used to cool the air entering compressor 2. It is designed to cool 2670 pounds of air per second entering at 350° F and leaving at 120° F with a pressure drop of 10 inches of water.

Compressor 2: Compressor 2 is a ten-stage axial-flow compressor, rated at a volume of 22,000 cubic feet of air per second at a pressure ratio of 2.4. It has 100,000 horsepower available to drive it, furnished by three wound rotor induction motors.

Valves 6 and 7: Valves 6 and 7 are 6-foot- and $2\frac{1}{2}$-foot-diameter butterfly valves, respectively. They are used as compressor 2 bleed valves to match the compressor to the tunnel air-flow requirements.

Valve 8: Valve 8 is a 15-foot-diameter butterfly valve used to bypass the air around compressor 2 when the compressor is not required.

Exhauster building: The exhauster building houses two Cooper-Bessemer piston-type exhausters, giving a total exhauster capacity of 100,000 cubic feet of air per minute. The exhausters reduce the air density in the tunnel when the tunnel is operated on the aerodynamic cycle.

Valves 9 and 10: Valves 9 and 10 are 4-foot- and 20-inch-diameter butterfly valves, respectively. They are used to control the amount of air that the exhausters can pump out of the tunnel.

Flexible-wall nozzle: The flexible-wall nozzle produces supersonic flow through the test section; it consists of two flexible side walls of type 322 stainless steel 10 feet high, 76 feet long, and $1\frac{3}{8}$ inches thick actuated by hydraulically operated screwjacks; the top and bottom plates are fixed.

Test section: The test section is 40 feet long, has a cross section of 10 by 10 feet at the entrance, and is 10 feet high by 10 feet 6.120 inches wide at the exit. All test-section plates are type 410 stainless steel $1\frac{3}{8}$ inches thick.

Second throat: The second throat is another type nozzle used to save power by reducing the Mach number of the air leaving the test section before the normal shock wave. The two side walls are movable; each side wall consists of two hinged plates actuated by electrically driven screwjacks. The top and bottom plates are fixed.

Cooler 1: Cooler 1 is a finned-tube, water-coil-type heat exchanger, used to cool the air entering compressor 1. It is designed to cool 1880 pounds of air per second entering at 650° F and leaving at 120° F with a pressure drop of 3 inches of water.

Compressor 1: Compressor 1 is an eight-stage axial-flow compressor, rated at a volume of 78,000 cubic feet of air per second at a pressure ratio of 2.8. It has 150,000 horsepower available to drive it furnished by four wound rotor induction motors.

Valves 11 and 12: Valves 11 and 12 are 8-foot- and 4-foot-diameter butterfly valves, respectively. They are used as compressor 1 bleed valves to match the compressor to tunnel air-flow requirements.

Valve 13: Valve 13 is a 24-foot-diameter swinging-type valve, which is used to change the tunnel into either the aerodynamic or propulsion cycle of operation.

Exhaust muffler: The exhaust muffler is used to quiet the discharge air of the tunnel when it is operated on the propulsion cycle.

Control room: The control room is a sound-insulated, air-conditioned room from which the tunnel and model variables are controlled and monitored.

DAMPR room: The DAMPR room is a sound-insulated, air-conditioned room adjacent to the control room in which the automatic pressure-recording equipment and the manometer boards for visual pressure indications are located.

10-BY-10 FOOT TEST SECTION

The test-section plan view, cross section, and elevation views are shown in figures 2(a), (b), and (c), respectively. The upstream cross section at the end of the flexible-wall nozzle plates is 10 by 10 feet. The $1\frac{3}{8}$-inch-thick type 410 stainless steel side walls diverge 0° 22' each to a width of 10 feet 6.120 inches at the downstream end. Equally thick top and bottom plates are parallel. The location of the test rhombus is shown in figure 2(a).

The top and bottom plate openings for installation of model supports and auxiliary apparatus are identical. Either opening can be 20 feet long by 3 feet 6 inches wide maximum or some smaller increment depending upon the selection of insert plates. The tunnel insert plates cannot be altered; therefore, new inserts are required for passage or fastening of research apparatus to these plates. Model mountings as described under the section on MODEL SUPPORTS AND STINGS are mounted through these openings.

Personnel access doors 3 by 7 feet are located opposite each other at the downstream end of the test section on each side wall.

Two sets of upstream windows are located in the side walls. These 33-inch-diameter clear-opening windows are located $10\frac{1}{2}$ inches eccentric in 60-inch-diameter disks. The centers of the disks are 10 inches above the tunnel center line. Rotating the 60-inch disks enables the 33-inch-diameter windows to cover any portion of a 54-inch-diameter circle about the 60-inch-diameter circle center. One set of 33-inch clear opening windows is in a fixed location downstream from the other windows and is mounted $20\frac{1}{2}$ inches above the tunnel center line.

The whole floor of the test section is capable of being lowered to the first-floor level by means of four long screwjacks attached to each corner. Model installation is generally made through this 33-foot $4\frac{1}{8}$-inch by 10-foot clear opening by means of the special model dolly shown in figure 3. Two 25-ton traveling overhead cranes capable of running the length of the test-section housing building are available for model installation in special instances. These cranes also have 5-ton auxiliaries.

MODEL SUPPORTS AND STINGS

STING STRUT: The strut for sting-mounted models, as shown in figure 4, is mounted through the floor of the test section when supporting a model, and when not in use is completely retractable below the tunnel floor. The strut center line may be located between 14 feet 5 inches and 23 feet 5 inches from the floor datum line in 6-inch increments. The strut has a chord length of 48 inches and is 8 inches thick.

The center of rotation of the strut is located $9\frac{1}{2}$ inches below the test-section floor, and the angle of attack can vary from -5° to 20°. The radius of rotation is a maximum of 6 feet 10 inches, while the minimum radius will depend on the interference of the strut socket with the floor of the tunnel. The position of the strut is remotely indicated in the tunnel control room.

A terminal panel is located in the top of the strut where all electrical and pressure connections from the model are made. This panel is easily accessible by removing the fairings from the sting socket.

The rear portion of the sting, which must fit the sting socket in the strut, must be made in strict accordance with the dimensions shown at the top of figure 4. Allowable sting loads are also indicated in this figure.

SUSPENDED-MODEL STRUT: A suspended-model strut with a typical model installed is shown in figure 5. The strut details will vary with each model, but the operating mechanism will be the same and will be furnished by the NACA. All struts must be designed to fit this operating mechanism. Any details not included in this Manual will be furnished on request.

Thickness of struts, which may vary from 3 to 10 inches, is limited by the travel of the bearing pads that support the strut in its housing.

The maximum permissible chord of the strut is 7 feet. However, in special cases, longer chord struts may be used, but these require special insert plates at one or both ends of the strut housing.

Angle of attack of the model is controlled by a screwjack mechanism which rotates the strut around a 3-inch-diameter pin located 7 inches above the inside surface of the tunnel top plate. The angle of attack can be adjusted through a total range of 20°. For example, if the screwjack mechanism is arranged to give a maximum negative angle of attack of -5°, the maximum positive angle will be 15°. However, it must be emphasized that it must be possible to adjust the model to 0° angle of attack in order to minimize starting loads.

The center of rotation of the strut may be positioned along the top of the tunnel in 6-inch increments between 11 feet 8 inches and 21 feet 8 inches from the tunnel joint datum line. This is without special insert plates.

The screwjack can be mounted on either end of the strut housing, depending on clearances to the tunnel structure.

In order to prevent leakage of air into the tunnel, the user must furnish a seal plate containing a seal groove for an inflatable seal which will be furnished by NACA Lewis Laboratory.

Instrumentation and electrical leads from the strut will lead to a terminal panel on top of the test section as shown in figures 2(b) and (c). Pressure tubing is connected to this terminal panel through quick disconnect blocks, electrical leads through AN connectors, and thermocouples through special polarized plugs.

AUXILIARY STRUT: An auxiliary strut, shown in figure 6, is provided to hold a plug-actuating mechanism or tail rake, furnished by the user, when a suspended model is used. Equipment must be made to fit the flange on the end of the strut, as shown in figure 7. The strut is designed to rotate about the suspended-model strut center of rotation at a radius of 147 inches. The leading edge of the strut may be located a minimum of 9 feet 5 inches and a maximum of 23 feet 11 inches from the test-section flexible-wall joint, with positioning in 6-inch increments. There are three more possible positions of the strut at 29 feet 5 inches, 29 feet 11 inches, and 30 feet 5 inches from the upstream tunnel joint.

All electrical cables and any instrumentation will lead to the same terminal panel on the top of the test section as used with the suspended-model strut.

MODEL INFORMATION

DELIVERY: The model shall be delivered to the Lewis Unitary Plan Wind Tunnel four weeks previous to the scheduled starting date of the tests if only calibrating work is to be done on the model. If there is the possibility of necessary extensive instrumentation work, the model should be delivered three weeks earlier.

MODEL SIZE: Figure 8 shows the maximum estimated projected frontal area allowed for a model plus support, at each Mach number. Since the model size is also limited by the tunnel pressure ratio available for starting and other factors such as shock boundary-layer interaction, figure 8 can be considered only a rough approximation. Therefore each model proposal must be evaluated independently and if starting appears to be marginal, a small-tunnel pilot investigation of the blockage and starting pressure ratio requirements will be required.

MODEL STRENGTH: The maximum allowable stresses for the critical loading conditions shall not exceed one-fifth of the ultimate or one-third of the yield, whichever is least. In addition, for members loaded as columns, the Euler critical load shall be at least three times the applied load.

The starting loads shall be assumed to be a normal force resulting from the maximum steady-state dynamic pressure of 730 pounds per square foot absolute at the test-section Mach number. The model is to be assumed to be at its maximum critical angle of attack. A force equal to the normal force is to be assumed to be acting in a plus or minus yaw direction.

All auxiliary parts of the model that will be exposed to the airstream and are nominally at zero angle of attack shall be checked to at least 10° angle of attack.

The model shall be constructed of materials capable of withstanding the contemplated loads, pressures, and temperatures associated with the modes of testing as summarized under the section called OPERATING CHARACTERISTICS.

FUSELAGE SPECIFICATIONS: The fuselage shall be constructed of steel, aluminum, magnesium, or plastic capable of withstanding contemplated forces and temperatures, yet be as light as feasible. The clearance between the fuselage and sting will depend upon the deflection characteristic of the balance and cannot be specified. An effort should be made to electrically indicate fouling between the sting and the model.

Sufficient access panels or cutouts shall be provided to facilitate maintenance of all working parts and instrumentation contained within the fuselage.

WING AND CONTROL-SURFACE SPECIFICATIONS: Wing and tail surfaces shall be made of steel to minimize aeroelastic effects and shall be polished. Tail surfaces shall be made easily removable. Variable control surfaces which are to be deflected during testing should be provided, whenever possible, with remote actuation and position indication.

PRESSURE-ORIFICE AND TUBING SPECIFICATIONS: All pressure orifices shall be flush and perpendicular with the external surfaces and shall be not less than 0.040-inch inside diameter. Tubing connected to such orifices shall be at least 1/16-inch outside diameter, and the 1/16-inch tubing run shall be short, increasing to 1/8-inch-outside-diameter tubing as soon as feasible. Whenever possible, 1/8-inch-outside-diameter tubing should be used throughout, especially if the pressure to be measured is less than 200 pounds per square foot absolute.

All instrumentation tubing shall conform to the following table of allowable sizes. It shall be type 347 fully annealed stainless steel whenever the size is smaller than 1/8-inch outside diameter or whenever it is used for rakes or serves any structural purpose. Otherwise, soft copper tubing may be used.

Tubing O.D., in.	Wall thickness, in.	
0.0625	0.012	
.090	.0145	
.125	.018 to .032	Stainless steel
.125	.025 to .032	Soft copper
.188	.035	Soft copper

A maximum of three hundred tubes may be used with each model strut. Tunnel users are expected to furnish the model with tubing of sufficient length to allow the attachment of quick-disconnect blocks, which will be furnished by NACA Lewis Laboratory. These quick-disconnect blocks are to allow for quick installation of the model in the tunnel, since the pressure instrumentation may be prefabricated on special shop model stands that duplicate the model strut installation in the tunnel.

SPECIAL CONSIDERATIONS FOR MODELS FOR INLET INVESTIGATION: Models designed for inlet investigation shall generally be constructed as described previously. The model body shall duplicate the full-scale configuration for sufficient distance to assure inlet and boundary-layer flows corresponding to the full-scale configuration. All canard surfaces and/or other appendages to the forebody shall be included. Ducts through the fuselage or nacelles shall be duplicated to the engine-inlet station. Mass flow shall be controlled by choking the duct exit with a parabolic-shaped plug. In scaling down the model, any boundary-layer bleeds shall be modified to correct for the difference in Reynolds number. Provision shall be made for the installation of dynamic-pressure pickups on the model at locations such that indication of flow instability (buzz) can be obtained. The dynamic pickups will be furnished by NACA. Rakes shall be located in the model to determine pressure recovery and pressure distributions at suitable duct stations. These rakes shall have tubes that conform to the table of allowable sizes and shall be rigidly supported as well as have an airfoil-type chord section. Any soldering on the rakes shall be silver-soldering. Rake tubes should be so spaced that they measure equal areas of the duct in order to facilitate pressure integration. The mass-flow ratio will be determined by calculations based on the choked duct exit area and the static pressures measured upstream of the duct exit.

MODEL MASS-FLOW PLUG DESIGN, MODEL COMPONENT ACTUATORS, AND POSITION TRANSDUCERS: A typical plug that is used to control the air flow through a model is shown in figure 9. The design of a plug and actuator of this type requires that the plug itself shall have a parabolic contour so that the model exit area is directly proportional to the plug position. The plug drive shall be either an electrically driven screwjack or a hydraulic cylinder. When an electrically driven screwjack is used, it must be protected at both ends of its travel by limit switches so that it cannot damage itself or the model by traveling too far in either direction. When a hydraulic cylinder is used, it must be sized so that its stroke does not exceed the safe movement of the plug. It must be the cushioned type if it is to move rapidly, and must be free of external leaks during cycling or standby operation.

The plug or its operating mechanism shall have a position transducer connected to it so that the plug position is remotely indicated. This shall be either a selsyn geared to the plug drive so that it shall make at least 20 revolutions per inch of plug travel, or a ten-turn precision potentiometer geared to the plug drive so that full plug travel will turn the potentiometer at least eight turns. This potentiometer shall have a total resistance of approximately 1000 ohms and shall be linear within ±0.1 percent. In certain cases, linear slide wires may be used; these must also have a total resistance of approximately 1000 ohms and be linear within ±0.1 percent.

Items such as screwjacks, hydraulic cylinders, electric motors, selsyns, potentiometers, and slide wires must be capable of withstanding the tunnel test-section operating conditions.

The systems described for a typical plug drive and position indication should be used in all model component actuators. If others are to be used, they must meet with the approval of the NACA Lewis Laboratory.

ELECTRICAL CONSIDERATIONS: Any wire or electrical device used in the tunnel test section must be capable of withstanding the test-section operating conditions. All models should be wired with stranded copper, silver-coated, teflon-insulated wire of a size that will conservatively carry the necessary current. Pressure transducers, strain gages, vibration pickups, and other low-voltage equipment that requires shielded wire should have each individual group of wires cabled inside a metal braided sheath. Each model device such as a motor, pressure transducer, solenoid, and so forth, shall have its wires terminate in an AN connector to match those existing on the appropriate strut terminal panel. Sufficient lead length should be allowed to reach the terminal panel easily and also allow for any angle-of-attack movement of the model strut. Power circuits (2 amps or more 28 volts D.C. or 5 amps or more 120 volts A.C.) shall terminate in plugs AN 3106-24-10P. Several circuits may be grouped in a single plug. Circuits requiring shielded wire should terminate in plugs AN 3106-14-6P with one connector and group of wires for each device. Wires for small motors, limit switches, selsyns, and so forth, should terminate in plugs AN 3106-16S-1P. Again, several circuits may be grouped in single plugs. The plugs listed will fit the AN connectors provided at the strut terminal panels. The NACA will provide all wiring from the terminal panels to the control room. A list of the permanent AN connectors as they exist on each strut terminal panel is shown in the following table. A column showing the type of cable from this terminal to the control room is also shown:

Quantity	AN Connector	Cable type	Wire length from model
Suspended-model strut terminal			
8	3100A-24-10s	6 conductor No. 9 wire	To be determined at time model position is decided
26	3100A-14s-6s	6 conductor No. 20 shielded wire	
20	3100A-16s-1s	6 conductor No. 16 wire	
Sting strut terminal			
5	3100A-24-10s	6 conductor No. 9 wire	Determined by sting length and connector position on terminal panel
16	3100A-14s-6s	6 conductor No. 20 shielded wire	
8	3100A-16s-1s	6 conductor No. 16 wire	

Wiring diagrams showing all electrical devices in the model and how they terminate on AN connectors should be submitted to the NACA at least five weeks before the scheduled date of the test.

THERMOCOUPLES: All model thermocouples should be made with high-temperature glass-insulated thermocouple wire of as heavy a gage as practical. Consideration should be given to how much the wire might be abused by having to be moved or handled in the course of maintaining the model during testing. Leads from the model should be long enough to reach the appropriate strut terminal panel and should terminate in Thermo Electric Co. Type 2PSS plugs.

The suspended-model strut terminal panel contains wiring for twenty-five iron-constantan and twenty-five chromel-alumel thermocouples in five circuit Thermo Electric Co. Type JBW-5 panels.

The sting strut terminal panel contains wiring for fifteen iron-constantan thermocouples in five circuit Thermo Electric Co. Type JBW-5 panels.

MISCELLANEOUS: All removable parts shall have a minimum of fasteners and shall be doweled for accurate replacement. All screwheads on the surface of the model shall be filled with materials that will withstand the temperatures at which the tests will be conducted.

INSTRUMENTATION AND DATA PROCESSING

BALANCES: Balances for the measurement of model forces will be supplied by the Lewis Unitary Plan Wind Tunnel. Three-component bearing-type strain-gage balances are available for sting-supported models. These balances are of the self-contained internal strain-gage type. Ball and roller bearings are used to isolate the components. Actual measurement of the forces is made by Baldwin SR-4 strain gages mounted on cantilever beams. The three components measured are axial force, front normal force, and rear normal force. The balances contain interchangeable links, so there is a wide selection of capacities available. Figures 10, 11, and 12 show the 4-inch-, 5-inch-, and 7-inch-diameter balances, respectively. The figures also give the mounting dimensions required for their use. The following table gives the list of links available for each balance to give the required characteristics:

Axial force, lb	Front normal force, lb	Rear normal force, lb	Distance between front normal and rear normal links, in.
4-inch balance			
±100	±100	±100	12
±200	±200	±200	
±300	±400	±400	
±500	±600	±600	
±800	±1,000	±1,000	
±1,200	±1,500	±1,500	
±1,800	±2,500	±2,500	
5-inch balance			
±250	±1,000	±1,000	15
±500	±2,000	±2,000	
±750	±3,000	±3,000	
±1,000	±4,500	±4,500	
±1,500	±6,000	±6,000	
±2,250			
±3,000			
±4,000			

Axial force, lb	Front normal force, lb	Rear normal force, lb	Distance between front normal and rear normal links, in.
7- inch balance			
±1,000	±2,000	±2,000	21
±1,500	±5,000	±5,000	
±3,000	±8,000	±8,000	
±5,000	±12,000	±12,000	
±7,500	±16,000	±16,000	
±10,000			

The links will take momentary overloads up to 200 percent of their capacity without damage. Continual overloads of this magnitude may rupture the SR-4 strain gages. The steel in the links will take 500 percent of the rated capacity before failure.

When it is necessary to maintain close alinement between the model and the sting at the rear of a large model, an external rear normal link is sometimes used in place of the one within the balance. This arrangement also increases the pitching-moment capacity of the balance system by increasing the distance between the front normal and rear normal links. The external link is usually identical to the links within the balance. Additional bearings are also required at the rear. Details of the mounting of the rear link and bearings are engineered for each model. The NACA Lewis Laboratory will furnish the link.

If forces are to be measured on suspended strut models, a special balance is required. This type of balance is part of the suspension system within the strut. Forces are isolated by bearings or flexure plates, and measurement is made by SR-4 strain gages mounted on cantilever beams. Variations to adapt to particular models will be engineered as required.

Equipment is available in the shop area to check out and calibrate the balances. It is possible to apply any combination of loads to the balance. Loads are applied by motor- or hand-operated screwjacks. A strain-gage link is used for measuring the load applied. Equipment is also available for checking the calibrating strain-gage links against dead weights. After the balance is installed in the model, the same type of screwjack assembly is used for applying loads to the complete model both in the shop and in the tunnel. A heater, provided by NACA Lewis Laboratory, is installed around the balance to maintain the balance at a constant temperature during the tunnel run to eliminate changes in calibration and zero shift due to temperature variations.

ATTITUDE INDICATOR: A model attitude indicator system is available to show the true model angle of attack. This makes it possible to correct the strut position for sting and strain-gage balance deflections. The system consists of an angle-of-attack transmitter, shown in figure 13, which is placed in the model, and a receiver which is located in the control room. The overall accuracy of the system is $\pm 0.1^{\circ}$. Mounting the transmitter in the model as shown in the figure will allow it to monitor the model angle of attack from -5° to $+20^{\circ}$. For its proper operation, it requires four No. 20 wires connected to the terminals as shown in the figure.

PRESSURE MEASUREMENTS: All pressure tubing from the model strut terminal panels leads to an interconnection panel in the DAMPR room. This interconnection panel allows tubes from the model to be connected to pressure-measuring equipment on the main manometer board, control-room manometer board, or the DAMPR system. The DAMPR system, completely described under the section on DATA RECORDING AND COMPUTING, can accommodate five hundred and seventy-six tubes for automatic recordings of pressures that will be used as final data.

The main manometer board consists of a bank of one hundred and fifty-six tubes 96 inches long. The manometers are connected to wells in banks of twelve tubes, one tube of which is a reference tube (thirteen wells, eleven usable tubes each = one hundred and forty-three tubes), with a constant reference pressure kept on the well and reference tube.

Depending upon the pressures being read, the type of fluid used, and the accuracies needed, one of four reference pressures can be used in any combination on the wells. These pressures can be set within the following limits with the indicated accuracies:

0 - 16.71 pounds per square foot	±0.05 pound per square foot
418 - 696 pounds per square foot	±2.0 pounds per square foot
557 - 1393 pounds per square foot	±4.0 pounds per square foot
835 - 1950 pounds per square foot	±6.0 pounds per square foot

This main manometer uses either mercury or dibutyl phthalate only. It is used for visual reading only, that is, setting test conditions or determining when pressures are sufficiently stabilized to permit recording data.

The control-room manometer board consists of forty-eight tubes 45 inches long grouped as the main manometer but with its four wells referenced to atmospheric pressure.

THERMOCOUPLES: Thermocouple wiring exists from the strut terminal panels to an interconnection panel near the test section. At this point the alloy leads are connected to copper wires which run to the control room and to the automatic digital potentiometer (ADP). The ADP is described completely in the section on DATA RECORDING AND COMPUTING. Each bank of ten thermocouples has an alloy pair for remote compensation at the model interconnection panel. The temperature scanner in the control room and the ADP automatically switch in the correct compensating thermocouple for the group of thermocouples each one is reading.

CONTROL-ROOM EQUIPMENT: All data-recording equipment for the tunnel and model, including the schlieren image viewer, and the controls for the automatic pressure-recording equipment are located in the control room. In the control room, panel space is allocated for installing the controls and indicating equipment necessary to operate, control, and test the tunnel model. The panel is designed to use Radio and Television Manufacturers' Association standard 19-inch relay rack panel sections. All interchangeable or replaceable control-room panel sections conform to these standards. Figures 14 and 15 show the general arrangement of the east and west control panels, respectively. These panels are made of relay rack panel sections and contain all the data-recording equipment for the model under test. A résumé of the available equipment follows:

Visual aids: Since the control room is located so far from the test section, closed-circuit television equipment has been installed. There are three television cameras complete with their power supplies and monitors. There are also four 24-inch television monitors and one 17-inch monitor installed in the control room. Any monitor is capable of being connected to any camera in any combination. Ordinarily, two television cameras are used as viewers for the two schlieren systems, and the third camera is used to view the model from some advantageous position while the model is in the tunnel for test.

Schlieren system: The tunnel is equipped with two identical schlieren systems which may be used alternately or simultaneously. These systems are located at the forward and intermediate sets of test-section windows and are capable of showing the flow patterns in the test section regardless of the position of the 33-inch-diameter clear opening windows in the 60-inch-diameter disks. Figures 16(a) and (b) show the plan and elevation views, respectively. Schlieren images are viewed by means of the television equipment previously described. Photographs of the images are taken by a 70-mm Beattie Veritron automatic data-recording camera; 1/100-second steady-state pictures or 1-microsecond flash pictures may be taken. A total of three hundred and twenty-five photographs $2\frac{1}{2}$ by $3\frac{3}{8}$ inches may be taken without reloading the camera magazine. In addition, a Fastax 16-mm high-speed motion-picture camera is capable of taking 100- to 4000-frame-per-second pictures of any image shown on the television camera. A lens turret containing three lenses allows magnification of any part of the standard image.

Temperature-measuring equipment: Temperatures are indicated on two Gilmore Industries temperature scanners (see figure 14). These are self-balancing strip-chart indicators and recorders. One is used for iron-constantan (I.C.) thermocouples and the other for chromel-alumel (C.A.) thermocouples. The I.C. recorder has a range of 0° to 400° F. The C.A. recorder has a range of 0° to 2500° F. If desirable or necessary, these ranges can be changed.

Each scanner is capable of scanning one hundred thermocouples in banks of ten, making a total of two hundred available temperature recordings. Any or all banks can be selectively controlled, and the scanner may be stopped on any particular thermocouple. While scanning, the instrument either indicates or prints while indicating, and may be stopped on any point for continuous indicating. A maximum time of two seconds is consumed for each individual thermocouple indication if the scanner traverses the full scale between successive readings.

On each bank a high- or low-temperature set point can be adjusted. If that point is reached during any scanning cycle, the scanner will stop and sound an alarm.

The same thermocouples that indicate on the scanner are also available to the ADP through a switching mechanism that is in operation during the time the automatic equipment is collecting data. During this time the scanner cannot be used.

Balance measurement: The strain-gage balance outputs are measured and recorded by four Bristol automatic balancing potentiometers (see figure 14). A strain-gage balance heater control is located in the same panel. A four-channel console on rollers is also available in the shop area to aid in checkout and calibration of the model balance. During data recording the strain-gage balance outputs are connected to the ADP.

Miscellaneous testing equipment: Two Bristol two-pen XXY recorders for plotting changing variables are available. These permit plotting two X variables against one Y variable. An example of such a plot would be that obtained by plotting two pressure-transducer output voltages generated by a model pressure against a plug position that was responsible for changing the pressure. Since the plug controls the mass flow through the model, it would be possible to plot pressure recovery against mass flow from the raw data.

Brush oscillograph recording equipment is available. This consists of one six-channel strip-chart recorder and two two-channel strip-chart recorders plus ten amplifiers, so that all recorders may be used at once. The recorders are suitable for electric or ink stylus, and the charts may be run at speeds of 5, 10, 25, 50, and 125 millimeters per second.

Photographic-type, multiple-channel oscillograph recording equipment is also available.

DATA RECORDING AND COMPUTING: The 10- by 10-foot tunnel data-recording equipment is divided into two categories, the control-room equipment just described for the control and immediate visualization of the test conditions and the automatic recording equipment which collects information for a general-purpose electronic computer. The results of an experimental investigation often modify the course of a test. With this in mind, the automatic data system was designed to prepare computed results in a form that is suitable for rapid analysis while the test is in progress. A digital computer was chosen because it is capable of any desired degree of accuracy in the calculations. In order to prepare the data for the computer, it was necessary to develop equipment to convert pressures, voltages, and mechanical positions to digital form and to store and record them for the computer. The various components necessary to do this are described in the following pages. The automatic data-recording system and the computer, with output equipment located in the tunnel control room, will be used as an "on-the-line" data-reduction system. Selected computed data will be displayed in the control room starting thirty seconds after the data point is taken. Data required for later extended analysis are stored on punched cards for read-out at the analyst's convenience.

AUTOMATIC RECORDING EQUIPMENT: The Lewis Laboratory has a system known as the Central Automatic Digital Data Encoder (CADDE) which is used by five of the laboratory's major test facilities to record digital readings from transducers of pressure, voltage, events per unit time, and mechanical position. A diagram of this system is shown in figure 17. The information is recorded on magnetic tape as four binary coded decimal digits with four additional characters for identification and computer instructions. The magnetic tape is the permanent record of the raw data. The computer will read-in and process the raw data simultaneously with its recording on magnetic tape. Computed results of immediate interest can be read out on paper tape which is typed out in the tunnel control room on either of two automatic typewriters. Converted raw data and intermediate results go to a high-speed card punch for tabulation by a line printer after the run is completed. Computed results typed out in the tunnel control room can also be sent to one of four automatic point plotters located near the typewriters.

Digital automatic multiple pressure recorder (DAMPR): The DAMPR system pictured schematically in figure 17 consists of four tanks with one hundred and sixty capsules mounted on each tank. The capsule, which is the primary sensing element of the pressure-measuring system, breaks an electric circuit when the pressures on either side of a diaphragm are equal within 0.01 inch of mercury. The tanks are evacuated to about 0.1 inch of mercury and then sealed off. When a reading is taken, pressurized air enters the tanks through a choked orifice. The time from the start of the pressure rise until the tank and model pressures are equal is measured by counting pulses generated by an oscillator in CADDE. When the tank pressure equals the model pressure the circuit between the oscillator and counter is opened by the capsule. The number in the counter is proportional to the time required for the tank and model pressure to be equalized. This number is stored in a three-hundred-channel magnetic core memory for read-out to the magnetic tape handler and computer at the completion of the pressure scan.

The scan time (i.e., the time required for the pressure to rise to its maximum) is ten seconds, and the repetition rate is once per minute. The oscillator generates approximately 1000 pulses per second, so that the resolution of the pressure-measuring system is equal to 0.0001 of the upper pressure limit for the tank. The four tanks have pressure limits of 2,500, 5,500, 12,000, and 20,000 pounds per square foot absolute.

The three hundred copper pressure lines from the tunnel are terminated on an interconnection panel near the DAMPR tanks. The input to five hundred and seventy-six capsules is also brought out on this panel so that any model tube can be jumpered to any capsule. The remaining sixty-four capsules are used to determine the slope and origin of the pressure-time line by applying known pressures to the capsules. Since the memory of CADDE is limited to three hundred channels, a model requiring more than three hundred channels would use a sequential scan of the four DAMPR tanks and would require thirty-five seconds for the complete scan.

Automatic digital potentiometer (ADP): The ADP is a self-balancing multichannel millivolt meter with a digital read-out. It contains four separate balancing units with ranges of -3 to 17 millivolts, -2 to 38 millivolts, and 0 to 40 millivolts. The potentiometer indicates a voltage as a percent of the range. The four units balance sequentially, and the reading is transferred directly to the tape handler and computer without intermediate storage. The potentiometer balances and reads out at the rate of six channels per second during the scan time of the DAMPR tanks. Therefore, 60 voltages can be measured during this ten seconds without slowing down the recording process. The instrument can read up to 200 voltages but will delay the transfer of the memory data to the tape handler and computer.

The input switch gear for the balancing units can switch thermocouple cold junctions (100° F) of I.C. or C.A. in series with the input voltage on any channel. A remote compensation thermocouple system, as described for the control-room temperature scanner, is used for thermocouple inputs.

Any type of voltage divider or strain-gage device having an impedance of less than 500 ohms can be measured with the ADP. A 40-millivolt power supply calibrated against the ADP standard cell is available for use with voltage divider networks such as the retransmitting slide wires on the Bristol potentiometers located in the control room.

Events per unit time (EPUT): Any instrument which generates pulses at a rate proportional to the input signal can have these pulses counted in the CADDE memory. By feeding the pulses through a ten-second time gate, the number of events occurring in a known time interval can be recorded and sent to the computer. Output of a tachometer or fuel flowmeter could be measured in this way. The total number of counts cannot exceed 100,000, and the counting rate cannot be greater than 20,000 counts per second. When more than 100,000 counts are generated in ten seconds, the length of time required to reach 100,000 counts is then recorded.

Automatic control-room monitor: In order to provide a single log of test conditions, a monitor system has been provided to collect information automatically from the control-room instruments. The monitor accepts inputs from mechanical counters and voltage sources. Reading number, time, schlieren and manometer picture numbers, oscillograph trace numbers, tunnel wall Mach number setting, and shaft position settings are converted to digital form and typed out on the monitor typewriter in the tunnel control room. Analog to digital converters having a visual indication of the setting are available to indicate and record synchro shaft positions to an accuracy of one part in ten thousand. Voltage inputs are converted to digits by an automatic digital potentiometer. Thermocouple voltages are measured by switching a 100° F reference junction in series with the thermocouple being sampled.

The monitor can accept twenty-four mechanical contact closure inputs and twenty-five voltage inputs. The monitor scans all of its inputs every time any control-room device is interrogated for an automatic read-out. It samples at the rate of 1.5 channels per second.

Contact closure devices: There are sixteen data bits to each binary coded decimal word recorded on tape and sent to the computer. A bit is present in a data word if there is a ground on the input to the shift register at the time it is loaded. The shift register is an electronic unit in which all numbers are assembled immediately prior to being recorded on a magnetic tape. A switching device located in the tunnel control room makes it possible to read up to twenty-five channels of information consisting of the presence or absence of a ground on any combination of the sixteen data bits. The combinations need not be meaningful as a binary coded decimal digit, since the computer can translate the combinations of bits into any desired meaning.

Analog to digital converters are available to count shaft rotations of devices in the model or in the control room. These converters have sixteen wires on which combinations of grounds appear to represent numbers up to ten thousand with an uncertainty of one part. These converters also have a four-decimal visual indication of their position. They can be used with synchromotors to indicate positions of mechanical parts in the models.

Other contact closure devices, such as rotary switches, stepping switches, or toggle switches, can be used to put information into CADDE. This information can be data, calibration constants, or computer instructions.

The computer: The information from the central data recorder is fed into an ERA 1103 (Engineering Research Associates) general-purpose electronic computer. The computer processes the data as it is received and reads out computed results while raw data are still being loaded into the machine. Computation instructions are contained in the machine for the test being run. The instructions for the preparation of the computer program must be received by the Lewis Laboratory's Mechanized Computing and Analysis Branch at least three weeks before the test date if "on-the-line" computing is to be used.

FACILITIES PROVIDED TO USERS

A total of 616 square feet of office space in two offices is provided for engineering personnel, and locker facilities are provided for all mechanical personnel.

SHOP MODEL STANDS: Four model stands are located in the shop area, which facilitate checking the model and making changes in the model or its components prior to its tunnel installation. Two stands are provided for sting-mounted models, one of which is shown in figure 18, and two stands are provided for suspended strut models, one of which is pictured in figure 19.

In the sting-mount model stand, the model is mounted exactly as it will be in the tunnel using the same sting. The sting is fastened at the rear of the stand, and the model overhangs the front of the stand where holes are located in the bedplate for mounting any instrumenting or testing equipment. The bedplate of the stand is 27 feet long, and the model center line is located 48 inches or 60 inches above the bedplate depending on whether a spacer is used in the stand. A connector panel is available at each stand which is identical to the panel installed in the strut for connecting instrumentation. This panel makes it possible to check all instrumentation in the model before it goes into the tunnel and provides for quick installation.

In the suspended strut model stand, the model is suspended exactly as it will be in the tunnel using the same strut. The model is supported by its strut from an overhead pipe suspended between two columns 17 feet 10 inches apart. The pipe itself is 10 feet $9\frac{1}{4}$ inches above the floor with the model hanging 48 inches from the floor. The model can be positioned in three different places on the stand, each 60 inches apart.

EQUIPMENT: The wind-tunnel shop contains an overhead 20-ton-capacity crane and a collection of machine tools including a lathe, milling machine, Do-All bandsaw, and several drill presses and bench grinders. A 36-inch light-gage roll, 60-inch light-gage bending brake, 48-inch light-gage shear, 24-inch throat Whitney-Jensen punch, and a Beverley throatless shear are available for sheet-metal work. Various sized surface plates are available for setup and layout work. There are several types of hand trucks and a 24- by 36-inch elevating table of 2000-pound capacity for handling model parts too big or heavy for easy hand lifting or carrying.

An acetylene gas, electric arc, and a heliarc welder, as well as a small spot welder, are available.

A tool crib located in the shop area has available a complete line of hand tools including some hand power tools.

A user supplying a model for testing in the tunnel will be assigned a model stand that duplicates the tunnel strut that will actually be used to test the model, and sufficient shop space with work benches and storage racks to work on his model. He will be issued a set of tool checks that will enable him to borrow any tool-crib tools.

POWER, AIR, AND HYDRAULIC SYSTEMS: At either the shop model stand or the tunnel test section the following types of electrical energy are available:

440-volt, 60-cycle alternating current three-phase
208-volt, 60-cycle alternating current three-phase
208-volt, 60-cycle alternating current one-phase
120-volt, 60-cycle alternating current one-phase
208-volt, 400-cycle alternating current three-phase
208-volt, 400-cycle alternating current one-phase
120-volt, 400-cycle alternating current one-phase
28-volt, direct current

125-pound service air and vacuum are also available at both the model stand and the tunnel test section.

When the model is installed in the tunnel test section the following services are available:

(1) 125-psig dry air, 2 pounds per second maximum continuous supply
(2) 40- to 150-psig dry air, 100 pounds per second; supply must be arranged for
(3) Hydraulic pumping unit for actuation, capable of pumping up to 10 gallons per minute at 3000 psig

FUEL SYSTEMS:

Gaseous system: The gaseous fuel system is designed to handle fuels that are in that state. It can deliver to the test section 1800 pounds of fuel per hour at a pressure of 200 psig. The system can be operated at reduced pressure with a corresponding decrease in the flow rate. Fuel is supplied to the system by large tank trailers in which the gas is stored under high pressure. Fuel flow is measured in orifice runs.

Liquid fuel system: The liquid fuel available at the tunnel test section is furnished by two pumping systems. These are the pilot system, which can furnish 0 to 5 gallons per minute at pressures up to 200 psi, and the main high-pressure system, which can furnish 0 to 228 gallons per minute at pressures up to 500 psi. Since the main high-pressure system consists of three pumping units, two of 70-gallon-per-minute capacity and one of 88-gallon-per-minute capacity, it is possible to pump three different types of fuel simultaneously.

Fuel flow is measured in the fuel house with rotameters that have an accuracy of ±1 percent of scale. The fuel viscosity can also be measured with a Fisher and Porter viscosimeter, which has a range of 3 to 0.3 kinedynamic units.

The fuel is filtered so that all particles down to 0.0005 inch are removed before the fuel reaches the tunnel test section.

Remote-reading flowmeters are available for use in the control room.

JET-EFFECTS MODEL: For making jet studies, the model shown in figures 20 and 21 is available. The model is a body of revolution 12 inches in diameter with the inside divided into three separate concentric ducts by shrouds. These are called primary, secondary, and tertiary ducts, as shown in figure 21. These ducts are completely independent of each other, and each has its own air-measuring and control system located outside the tunnel as shown in figure 20. These ducts are sized so that the maximum air flows through them are the following percentages of the maximum total flow: primary, 70 percent; secondary, 20 percent; and tertiary, 10 percent. Maximum total flow for this model is 60 pounds per second at 40 psig. This model can be operated with air at higher pressures, with a corresponding increase in the air flow; the air available to operate this model is indicated in the section entitled POWER, AIR, AND HYDRAULIC SYSTEMS.

A 5-inch strain-gage balance is used in the model to measure forces on the external shell of the model plus the forces of any of the internal shrouds that are connected directly to the external shell. The internal shrouds can be connected to either the lower strut end or the external shell, depending upon whether or not the forces on it are to be measured. In shroud connections, for any given shroud that is connected to the external shell, all of the shrouds larger than it must also be connected to the external shell; likewise, for any given shroud that is connected to the lower strut end, all shrouds smaller than it must also be connected to the lower strut end.

This model strut is mounted in the suspended-strut operating mechanism used for other suspended models. Details on design and possible location of this strut mechanism will be found in the section SUSPENDED-MODEL STRUT.

Modifications can be made to this model to accommodate different configurations. Joints are located in the strut, as shown in figure 20, and toward the rear of the model, as shown in figure 21, which enable the user to modify the entire model or just the rear portion. Details of the model and possible variations will be furnished at the request of the user.

OPERATING CHARACTERISTICS AND POWER COST ESTIMATING

OPERATING CHARACTERISTICS: Complete estimated operating characteristics of the 10- by 10-foot Lewis Unitary Plan Wind Tunnel are shown in figure 22. These curves show the dynamic pressure, test-section altitude, Reynolds number, test-section total pressure, and test-section total temperature for the complete tunnel operating range on either the aerodynamic or propulsion cycle.

OPERATING PROCEDURE: The tunnel is always started up or shut down on the aerodynamic cycle at low air densities to reduce the starting and stopping loads on the model. If a burning engine is being tested, the tunnel must be switched over to the propulsion cycle of operation after supersonic flow is established in the test section, before the engine can be started.

Propulsion-cycle testing operation: Starting procedure (requires approximately one hour twenty-five minutes):

(1) Valves 1, 3, and 4 are closed. Valves 2, 8, 9, and 10 are open. Valve 13 is in the 13a position.

(2) The flexible-wall nozzle is set for Mach 2.5 or above, depending on the Mach number at which testing is to be done. Because of the throttling action of valve 1 at Mach numbers below 2.5, the pressure differential across valve 13 is too high for its operation. Thus, switching from the aerodynamic to the propulsion cycle or vice versa during tunnel operation must be done at Mach number 2.5 or above.

(3) The exhausters are started and the tunnel pressure is brought down to approximately 200 pounds per square foot absolute. This requires twenty minutes.

(4) Compressor 1 is started and brought up to operating speed. If the testing is to be done at Mach numbers above 2.5, compressor 2 is started and brought up to speed; then valve 8 is closed. This requires fifteen or thirty minutes, depending upon the number of compressors required.

(5) With supersonic flow established in the test section, the tunnel pressure is brought up to atmospheric by allowing air to come in through valves 3 and 4 at a rate depending on the power rate of change, since the tunnel is limited to $7\frac{1}{2}$ megawatts per minute by the power company. This can require up to twenty-five minutes depending upon the tunnel Mach number.

(6) The exhausters are shut down; then valves 9 and 10 are closed.

(7) When the tunnel pressure reaches atmospheric, valve 1 is opened and valve 13 is put in the 13b position, thus changing tunnel operation from the aerodynamic cycle to the propulsion cycle. This requires ten minutes.

(8) The flexible-wall nozzle can now be changed to any Mach number setting.

(9) The engine in the model can be started any time after step (7) is completed.

Shutdown procedure (requires approximately one hour):

(1) The flexible-wall nozzle must be set for Mach 2.5 or above.

(2) Valve 13 is moved to the 13a position; then valve 1 is closed. This requires ten minutes.

(3) Valves 9 and 10 are opened, and the exhausters are started.

(4) Tunnel total pressure is reduced to approximately 200 pounds per square foot at a rate determined by the power rate of change. This requires up to twenty-five minutes.

(5) If compressor 2 is running, valve 8 is opened and compressor 2 is shut down.

This requires ten minutes.

(6) Compressor 1 is shut down. This requires ten minutes.

(7) Exhausters are shut down, and valves 9 and 10 are closed.

(8) Tunnel pressure is brought up to atmospheric by bringing air in through valves 3 and 4. This requires five minutes.

Aerodynamic-cycle operation: Starting procedure (requires approximately two hours):

(1) Valves 1, 3, and 4 are closed. Valves 2, 8, 9, and 10 are open. Valve 13 is in the 13a position.

(2) The flexible-wall Mach number is set at the desired testing point.

(3) The tunnel is purged by starting the exhausters and bringing the tunnel pressure down to approximately 200 pounds per square foot absolute; then dry air from the dryer building is brought in through valves 3 and 4. This process is repeated twice; then tunnel pressure is brought down to 200 pounds per square foot and held there for starting purposes. This procedure requires about one hour.

(4) Compressor 1 is started and brought up to operating speed. If the testing is to be done at Mach number above 2.5, compressor 2 is started and brought up to speed; then valve 8 is closed. This requires fifteen or thirty minutes, depending upon the number of compressors required.

(5) With supersonic flow established in the test section, the tunnel pressure can now be changed to the level at which the test is to be conducted. This can take up to twenty-five minutes, depending upon the power rate of change.

Shutdown procedure (requires approximately fifty minutes):

(1) The tunnel total pressure is brought down to approximately 200 pounds per square foot absolute. This can take up to twenty-five minutes, depending upon the power rate of change.

(2) If compressor 2 is running, valve 8 is opened and compressor 2 is shut down. This requires ten minutes.

(3) Compressor 1 is shut down. This requires ten minutes.

(4) Exhausters are shut down; then valves 9 and 10 are closed.

(5) Tunnel pressure is brought up to atmospheric by bringing air in through valves 3 and 4.

POWER COST ESTIMATES: The data presented here are to be used in estimating electrical power costs for the operation of the Lewis Unitary Plan Wind Tunnel. The average rate per kilowatt hour is expected to be between 8 or 9 mils during the fiscal year of 1956, depending upon the monthly consumption at the Lewis Laboratory.

With the tunnel operating on the propulsion cycle, the power consumed by the drive motors of compressor 1 over the Mach number range from 2 to 3.5 is approximately 120,000 kilowatts per hour. The tunnel can be operated between Mach number 2 and 2.5 with only compressor 1. At Mach number 2.5 compressors 1 and 2 can be operated together, depending upon desired tunnel conditions. At Mach number 2.6 to 3.5 both compressors 1 and 2 must be operated. The power required to drive compressor 2 varies from 50,000 kilowatts per hour at Mach number 2.5 to 80,000 kilowatts per hour at Mach 3.5.

The power required to operate the tunnel on the aerodynamic cycle is the same as the propulsion cycle or lower in proportion to the tunnel air density.

The drive systems and compressors may be operated slightly above or below the preceding power quotations to achieve particular test-section operating conditions.

In addition to these power figures, 900 kilowatts per hour for the compressor 1 drive and 750 kilowatts per hour for the compressor 2 drive must be added for the drive auxiliaries.

The cooling water system for the tunnel coolers requires 2000 kilowatts per hour.

Reactivation of the air dryer is necessary each day for propulsion-cycle operation but less often for aerodynamic-cycle operation, depending upon atmospheric conditions. Reactivation of the air dryer requires 9000 kilowatt hours of electrical energy.

Since the tunnel is always started or stopped on the aerodynamic cycle at low air densities, the exhausters are required for twenty to thirty minutes during tunnel starting and stopping when testing is done on the propulsion cycle. When testing is to be done on the aerodynamic cycle, the exhausters are required approximately one hour prior to tunnel operation for pumping down and purging the tunnel circuit and for most of the aerodynamic-cycle operation. The exhausters require a total of approximately 3000 kilowatts per hour during operation.

OPERATING TIMES AND LENGTH OF RUNS: The tunnel will operate some time between 10:00 p.m. and 7:00 a.m. five days per week under ordinary circumstances. The length of runs will be limited by either these times or by the dry-air requirements of the tunnel. When the tunnel operates on the propulsion cycle, the running time is limited by the air-dryer capacity; and it can be from thirty minutes in hot humid summer weather to over nine hours in cold dry winter. When the tunnel operates on the aerodynamic cycle, running time is not limited by the air-dryer capacity.

From the preceding discussion, it seems obvious that all testing on the propulsion cycle should be scheduled during the winter months whenever possible.

INFORMATION TO BE SUPPLIED BY THE USER

The user shall furnish the following information as soon as possible after the tests have been requested:

I. Model Details and Stress Analysis
   A. DRAWINGS OF MODEL
      1. Three-view suitable for inclusion in a report
      2. One complete set of drawings or sketches providing the following data pertinent to the model:
         a. All configurations to be tested; configurations shall also be listed in tabular form and cross-referenced to drawings
         b. Weight and center-of-gravity location for all configurations
         c. Materials employed in fabrication
         d. Heat treatments
         e. Types of bolts, screws, and other fasteners
         f. Weld dimensions
         g. Special methods of adhesive bonding
         h. Location of suitable reference stations for orientation of model in tunnel, including description of means of determining angular relation
         i. Location and identification of pressure rakes, probes, and orifices
   B. DRAWINGS OR SKETCHES OF MODEL INSTALLATION: These drawings or sketches shall show the relation between the model, the balance, the sting, and the sting support for sting-mounted models, as well as the model's location in the tunnel test section. For suspended models, the drawings shall show the relation between the model, the supporting strut, and its location in the tunnel test section. All dimensions should be refenced to the datum line of the test section as shown in figure 2(a). References to all detailed drawings and subassemblies should be clearly shown.
   C. TABULATED DATA: The detailed information listed in table I of this Manual shall be submitted. (Table I follows this text.)
   D. TEMPLATES: The company shall provide templates of all critical surface contours such as body and duct lip contours. A surface shall be considered critical if deviations from the prescribed ordinates would influence the test

results. The number of templates to be provided is not specified, but should be sufficient to establish the conformation of the surface with the desired ordinates.

E. DIAGRAMS: These shall consist of elementary wiring diagrams of all electrical devices and thermocouples plus line diagrams and description of model fuel, air, oil, or control systems.

F. STRESS ANALYSIS: A stress analysis of the model and sting or model and strut based upon the maximum loads anticipated in the tests and on the information supplied in the preceding section on MODEL STRENGTH shall be submitted to the Lewis Unitary Plan Wind Tunnel no less than five weeks prior to the scheduled starting date of testing.

Each section devoted to a detailed analysis shall contain a sketch showing the design forces and moments acting, the general equations for the stress distribution, and a concise statement of the assumptions and approximations involved.

G. REVISIONS: The Lewis Unitary Plan Wind Tunnel should be notified immediately of any changes to the model or model support system which involve the structural integrity of the installation, the test procedure or results, or the instrumentation. Reasons for the revisions should be stated. Additional stress analysis should be submitted if there has been any structural change.

II. Test Program

A. ITEMS: The proposed test program should include the following items:

1. List of the data desired: e.g., force data, duct-inlet pressure recoveries, mass-flow measurements, duct pressure distributions, temperature profiles, etc.
2. Tentative schedule of testing including model configurations, tunnel operating conditions, increments and ranges of the variable parameters, and the data to be taken at each condition.

III. Data Analysis Information

A. MODEL AREAS AND DIMENSIONS: All areas and model dimensions required for computation factors; tabular form preferred.

B. PLOTTED RESULTS: Desired form of plotted results.

C. COEFFICIENTS AND LOADS: Required force and moment coefficient accuracies and estimated loads.

D. PRESSURE MEASUREMENT: Required pressure-measurement accuracies and estimated extreme values relative to test-section dynamic pressure.

E. USER'S BALANCES: All calibration factors and calculative procedures of equipment necessary for data reduction.

F. SPECIAL DATA: Schedule of any special data required such as balance calibration, probe calibrations, etc.

SHIPPING ADDRESS

Material shipped to the Lewis Unitary Plan Wind Tunnel to be used as a part of a model or test should be addressed as follows:

Lewis Unitary Plan Wind Tunnel
NACA Lewis Flight Propulsion Laboratory
21000 Brookpark Road
Cleveland 11, Ohio

A return address and some type of model identification must be attached to the outside of the box.

TABLE I

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

LEWIS UNITARY PLAN WIND TUNNEL MODEL DATA

Date forwarded ____________

Model designation ____________ Model scale ____________

C.g. location	Longitudinal, ft from L.E. M.A.C.	
	Vertical, ft (above, below) fuselage reference	

Ⓐ Wing

ITEM		Total / Exposed
Type		
Area, sq ft		
Span, ft		
M.A.C.	Length, ft	
	Longitudinal location, ft	
	Vertical location, ft	
	Lateral location, ft	
Aspect ratio		
Tip chord length, ft		
Root chord length, ft		
Root chord location	Longitudinal, ft	
	Vertical, ft	
Taper ratio		
Airfoil section ①	Root	
	Tip	
Leading-edge radius		
Sweepback of quarter-chord line, deg		
Dihedral angle, deg		
Incidence angle, deg		
Geometric twist, deg		
Loading, lb/ft^2		
Tail length		

Ⓑ Fuselage

Length, ft		
Width, ft		
Depth, ft		
Frontal area, sq ft		
Fineness ratio	Overall	
	Forebody	
	Afterbody	
Side area, sq ft		

Ⓒ Balance

Pitch beam center ②		
Location	Longitudinal, ft	
	Lateral, ft	
	Vertical, ft	
	Percent, M.A.C.	

Ⓓ Inlet models

ITEM		Areas
Inlet		
Physical lip details		
Boundary-layer bleeds, etc.		
Plot of duct-area distribution	With accessory housing	
	Without accessory housing	
Typical cross sections		
Compressor inlet		
Engine-inlet air-flow matching characteristics		

Notes: ① Give orientation ② Balance center to be as close as possible to prototype c.g.

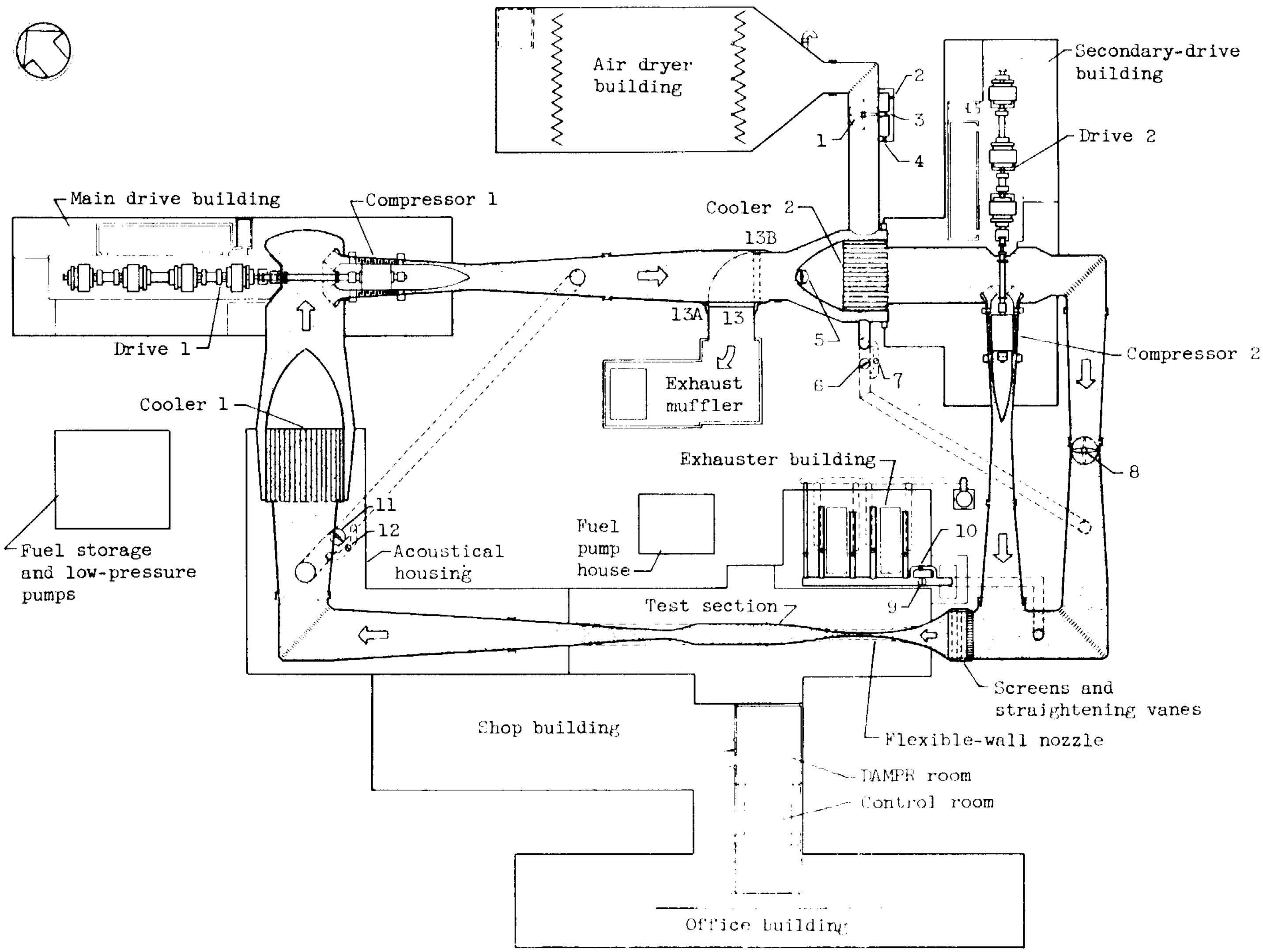
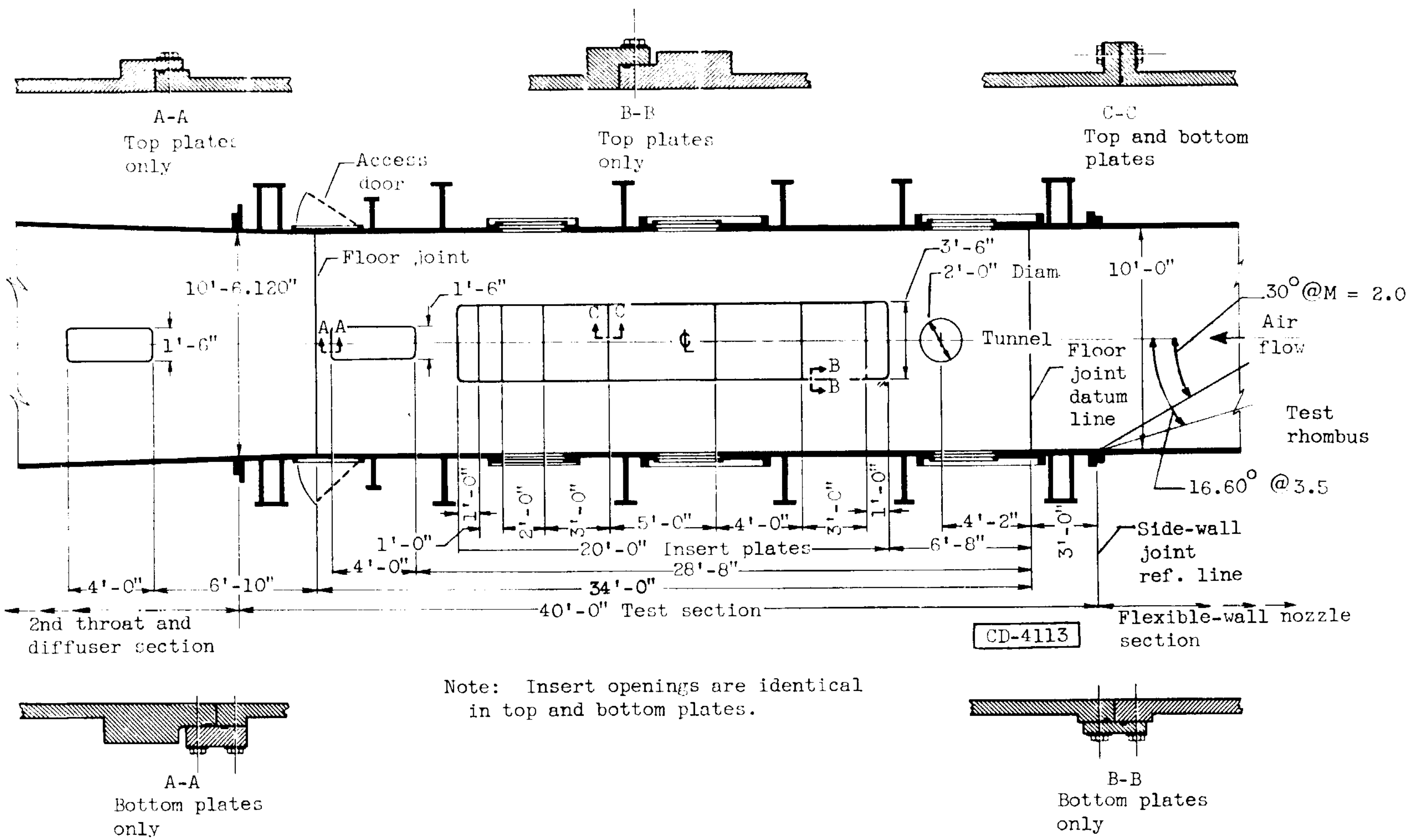
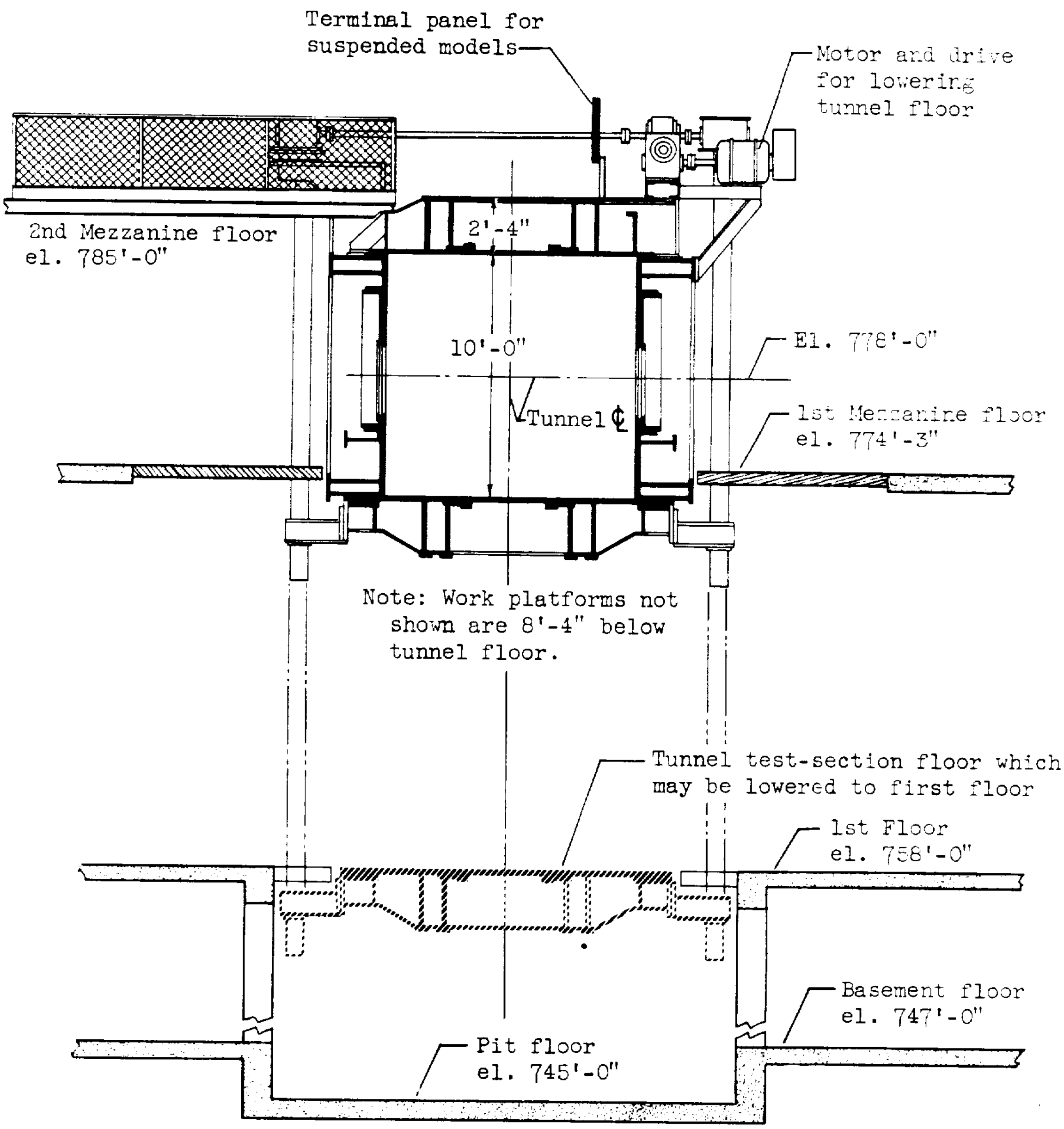


Figure 1. - Plan view of Lewis Unitary Plan Wind Tunnel.



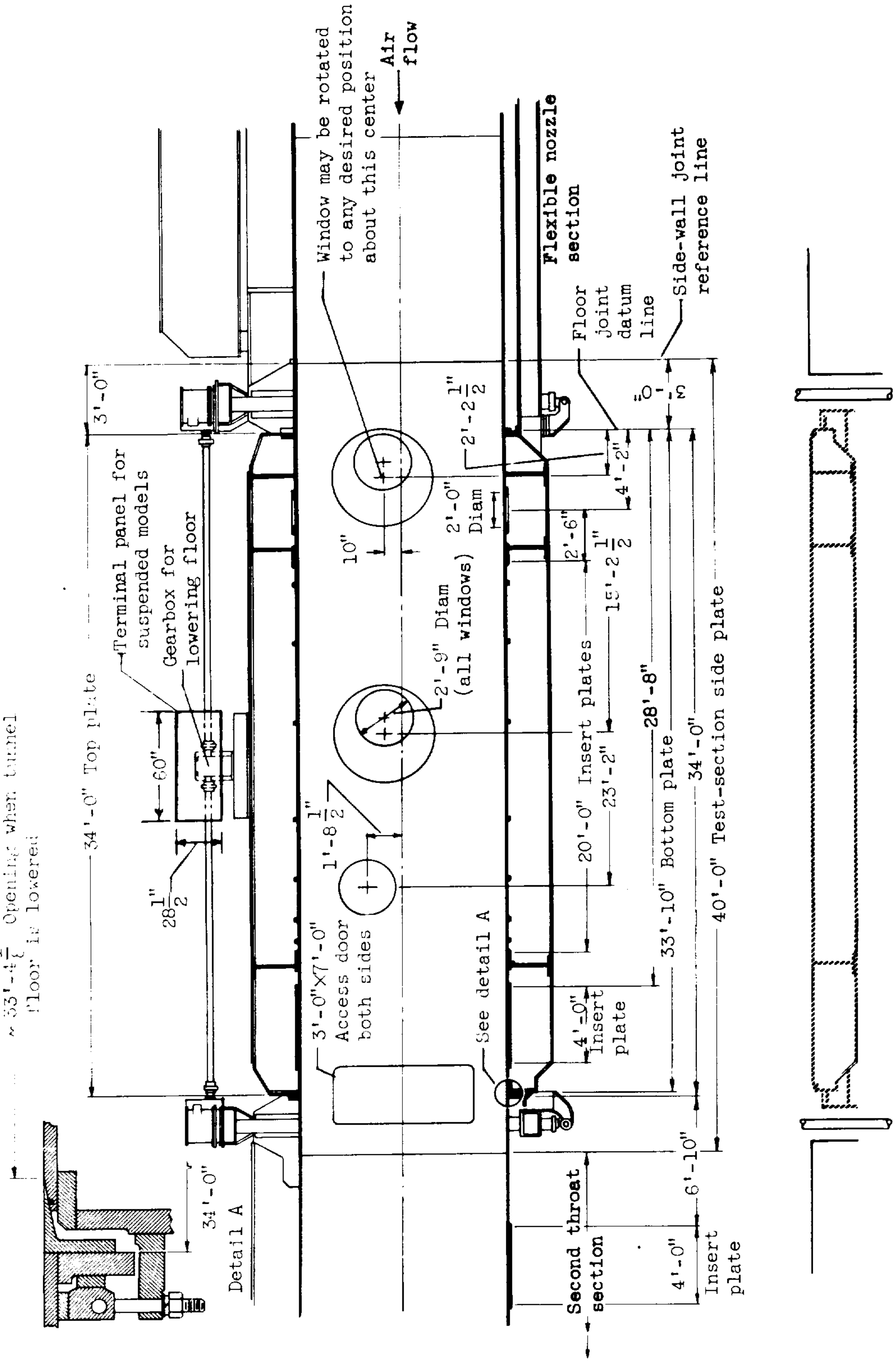
(a) Plan view.

Figure 2. - 10- by 10-foot test section, Lewis Unitary Plan Wind Tunnel.



(b) Cross section.

Figure 2. - Continued.



(c) Elevation view.

Figure 2. - Concluded.

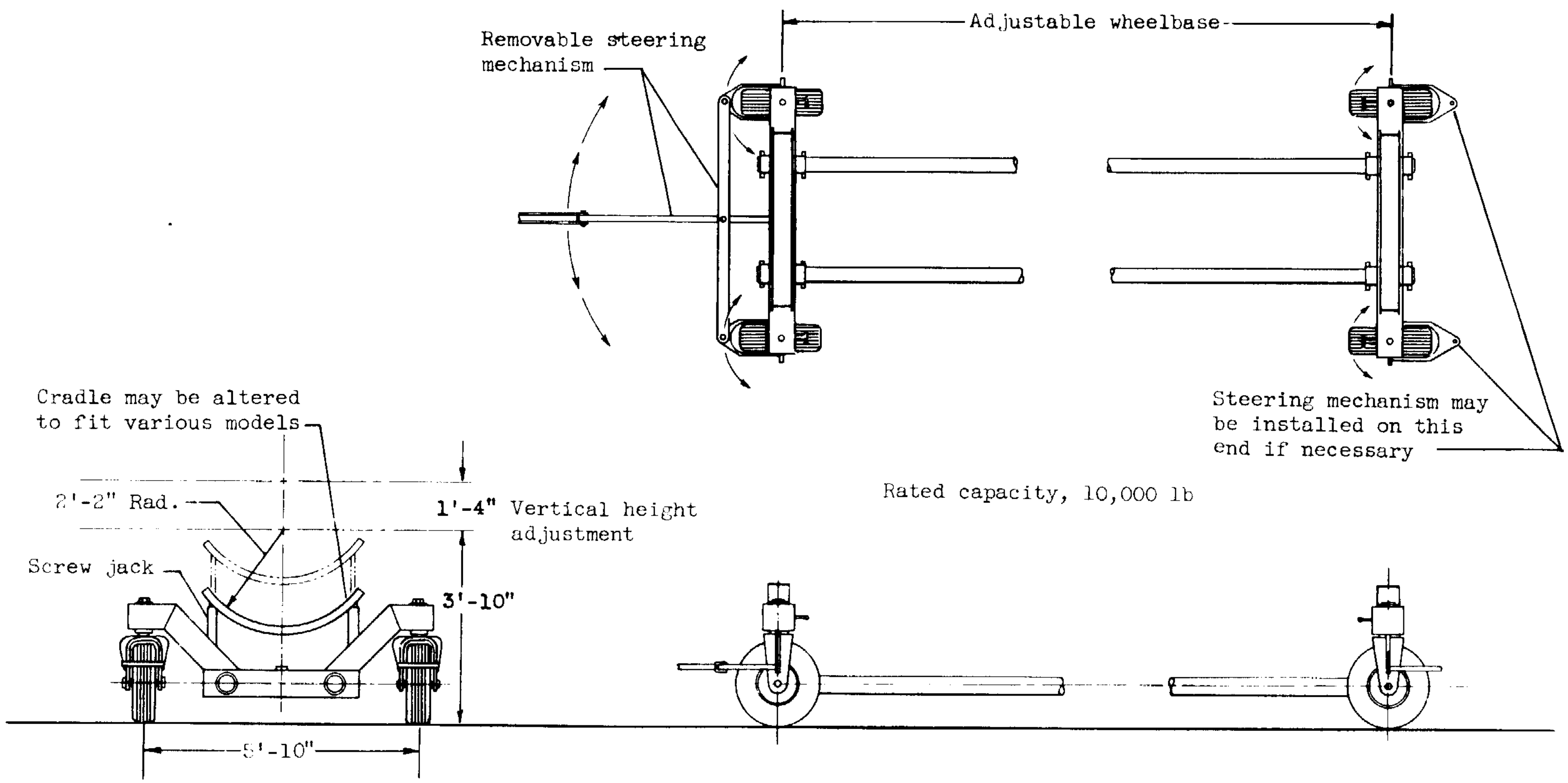


Figure 3. - Model transport dolly, Lewis Unitary Plan Wind Tunnel.

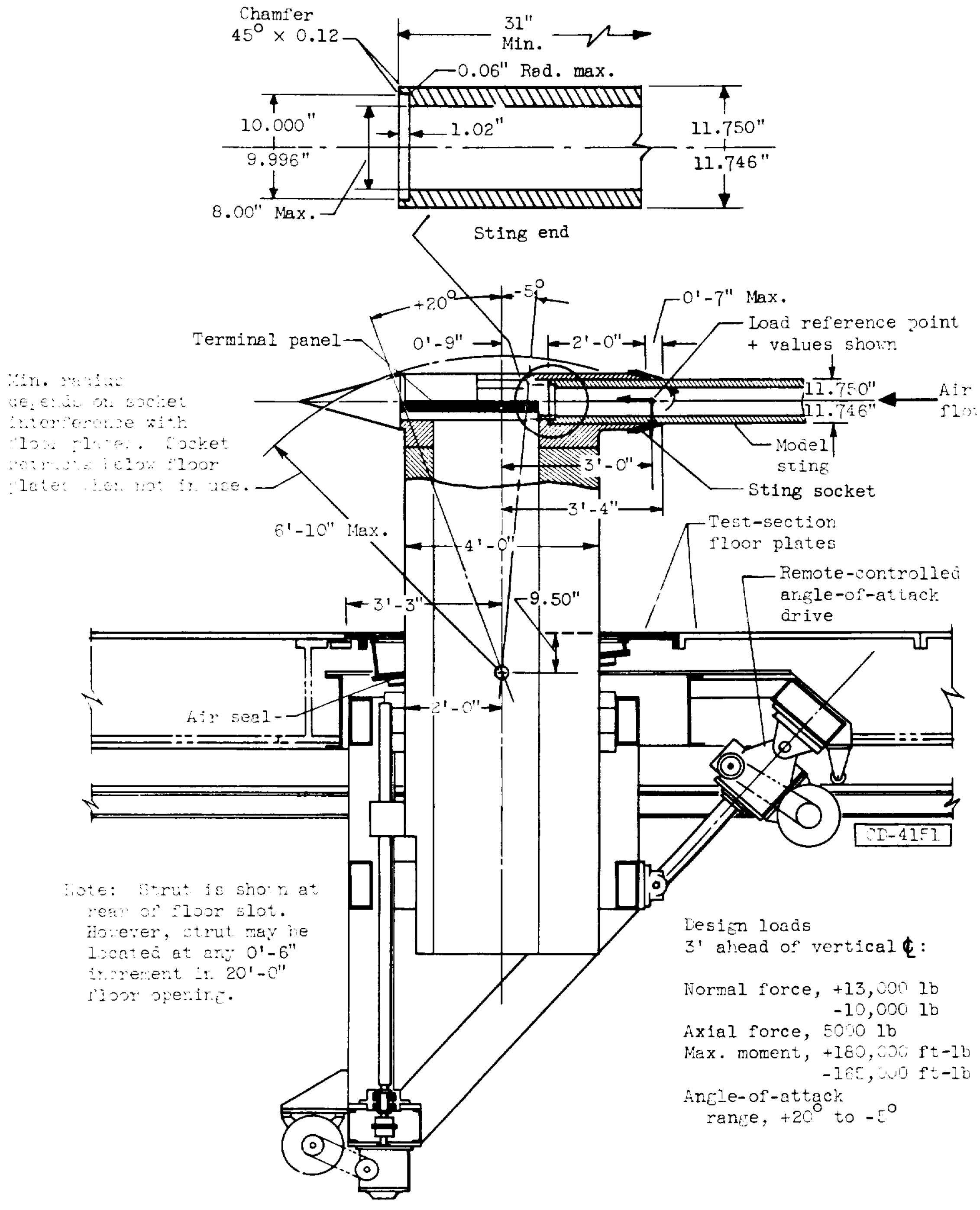
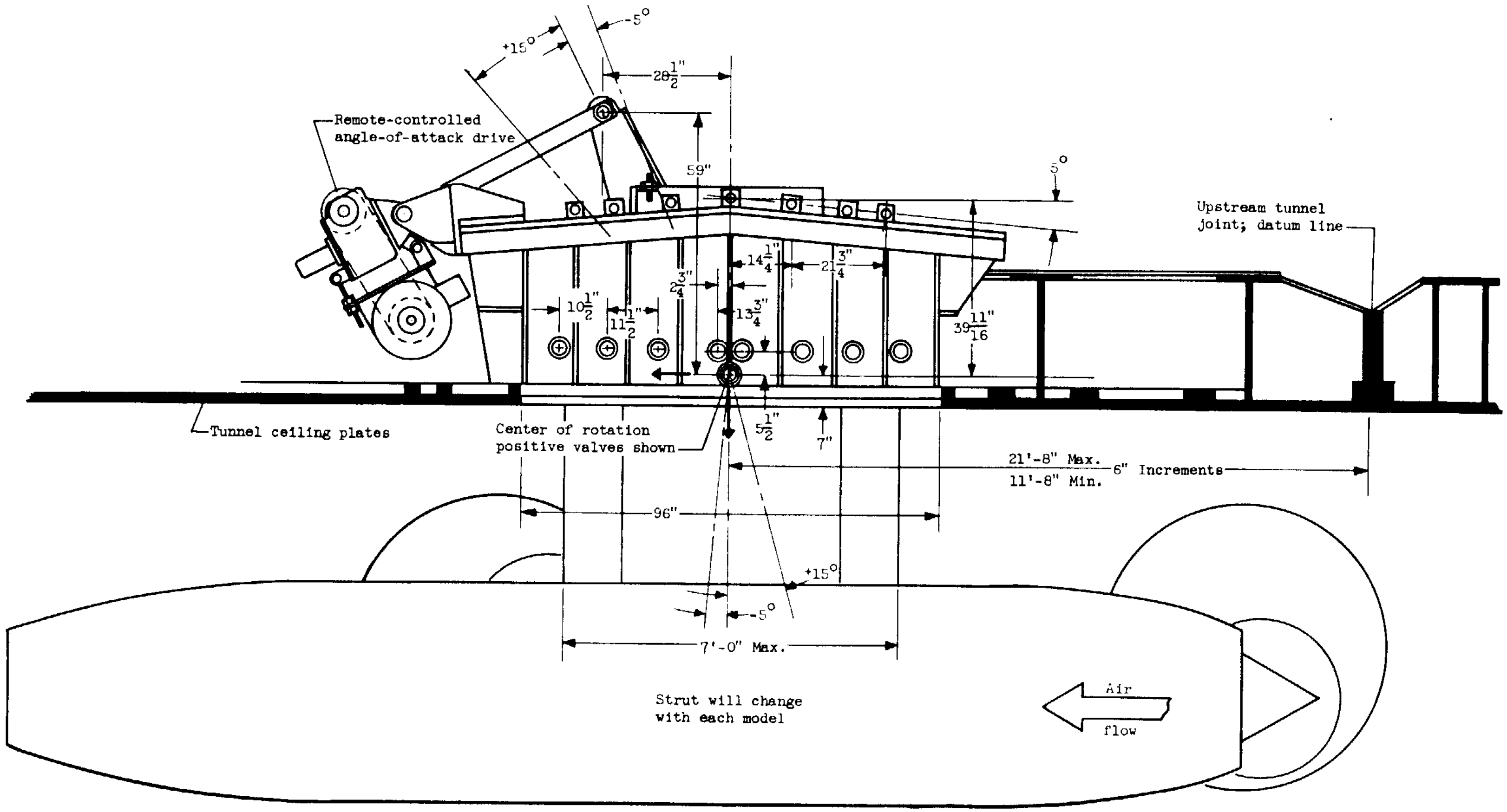


Figure 4. - Sting-mounted model strut, Lewis Unitary Plan Wind Tunnel.



Allowable loads at center of rotation:

Normal force ± 50,000 lb
Axial force ± 10,000 lb
Pitching moment ± 175,000 ft-lb

Note:
Allowable load = $\frac{\text{Ultimate strength}}{\text{Safety factor}}$
Min. safety factor is [illegible].

Figure 5. - Suspended model strut, Lewis Unitary Plan Wind Tunnel.

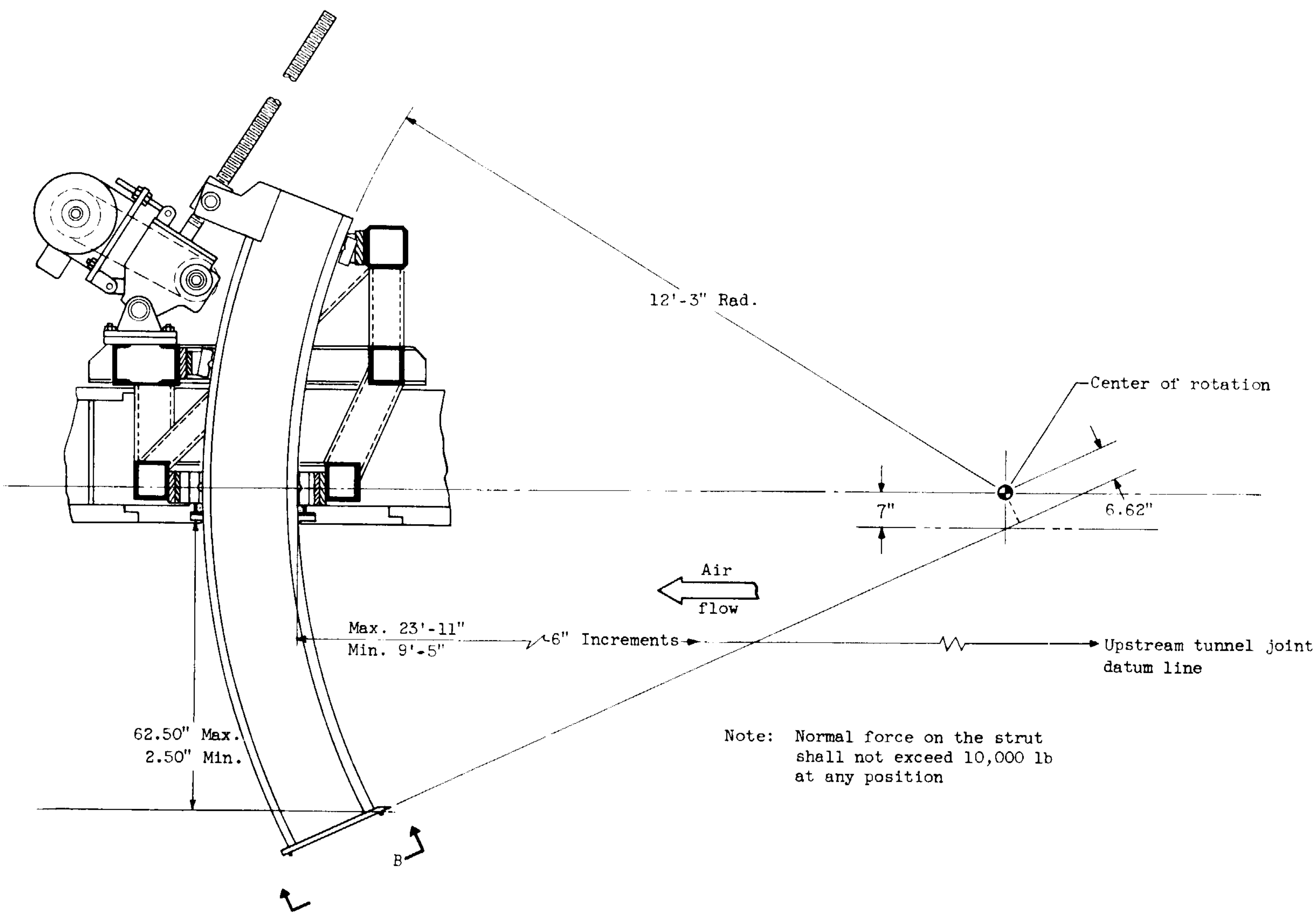


Figure 6. - Auxiliary strut, Lewis Unitary Plan Wind Tunnel.

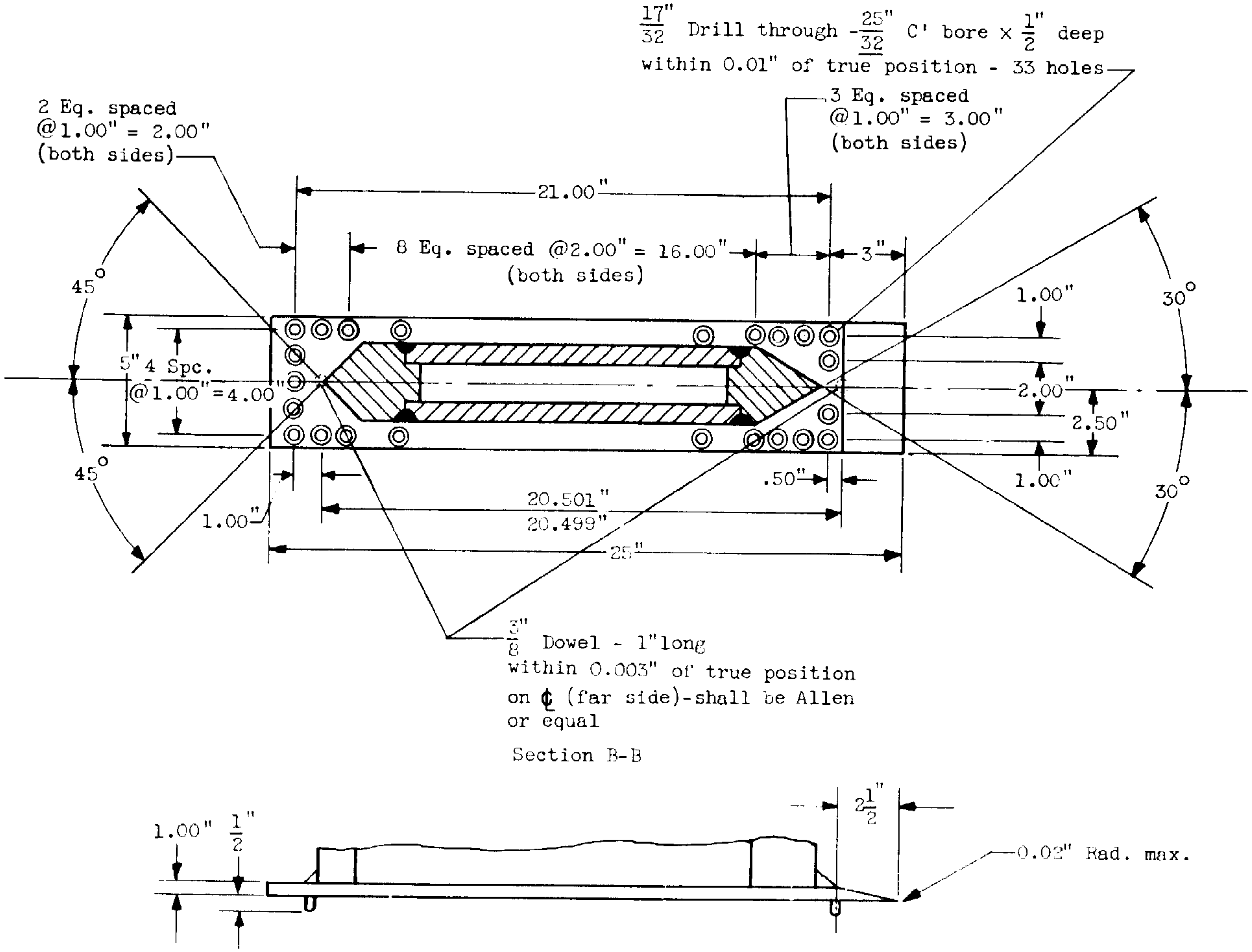


Figure 7. - Auxiliary strut joint, Lewis Unitary Plan Wind Tunnel.

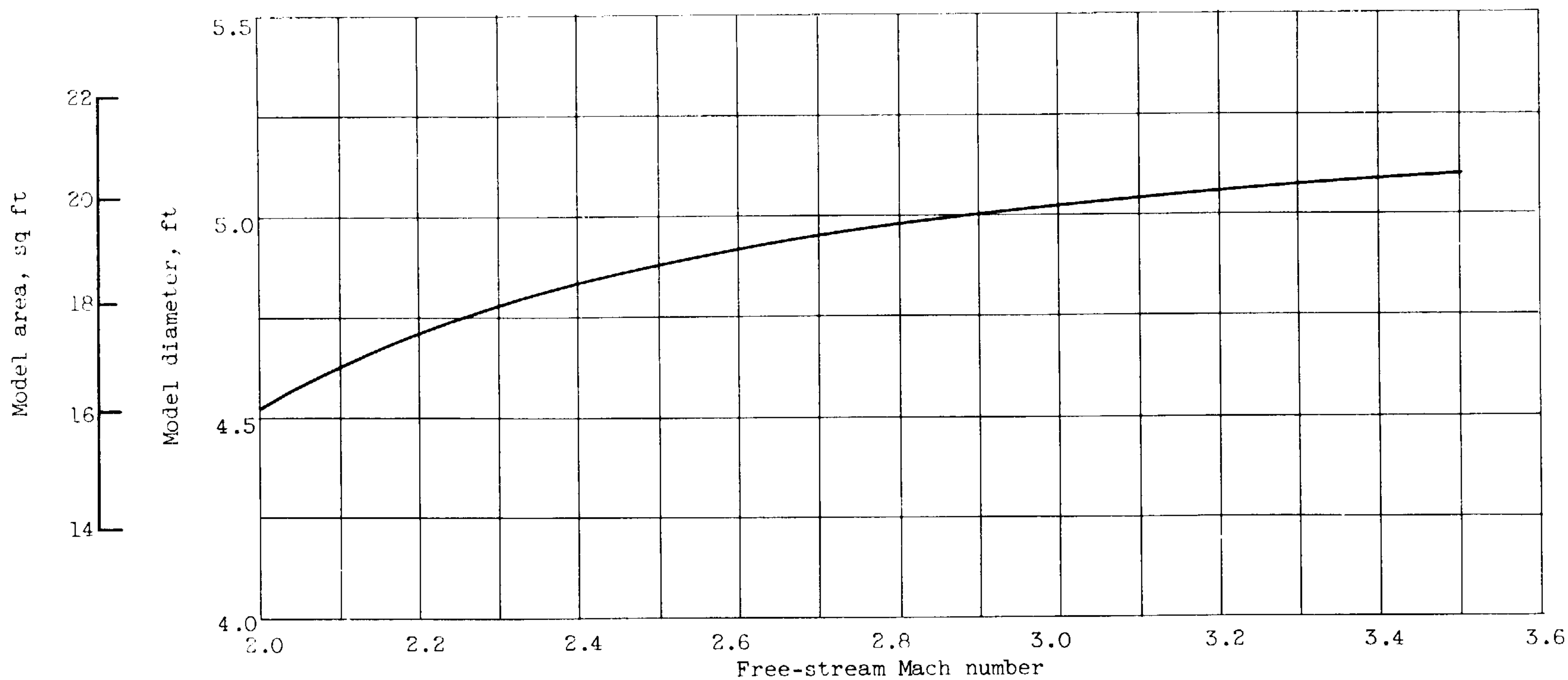


Figure 8. - Calculated allowable test-section blockage, Lewis Unitary Plan Wind Tunnel.

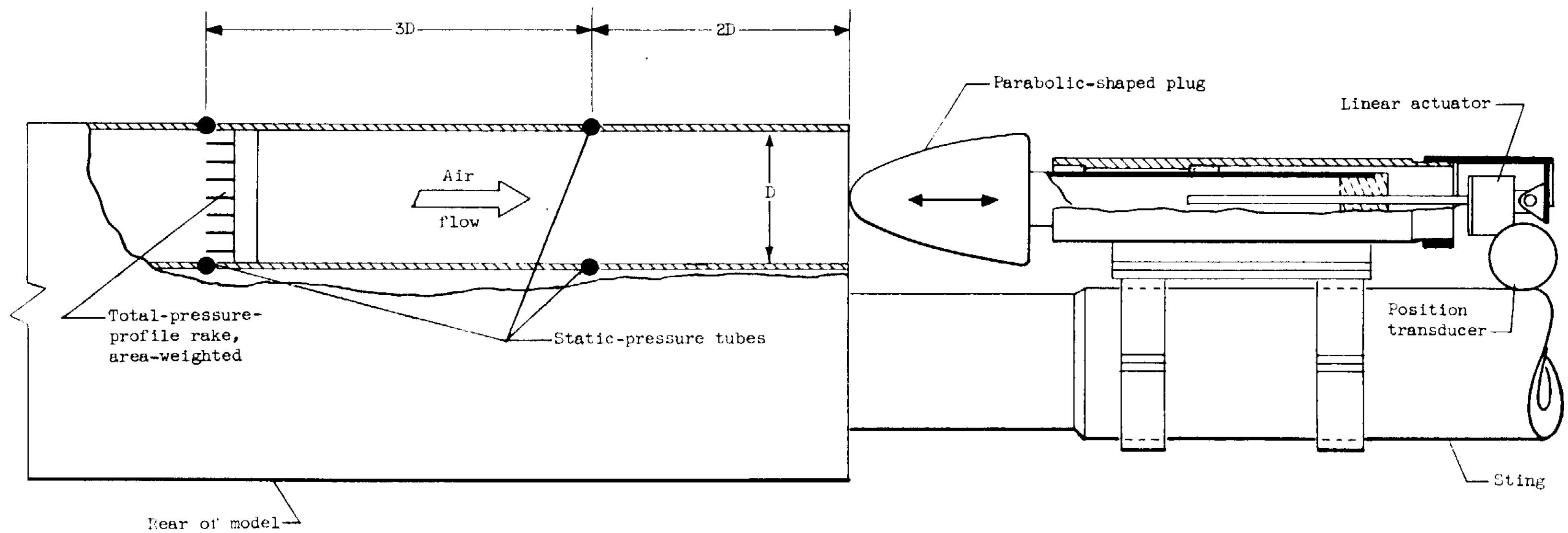


Figure 9. - Typical plug mechanism for sting-mounted model, Lewis Unitary Plan Wind Tunnel.

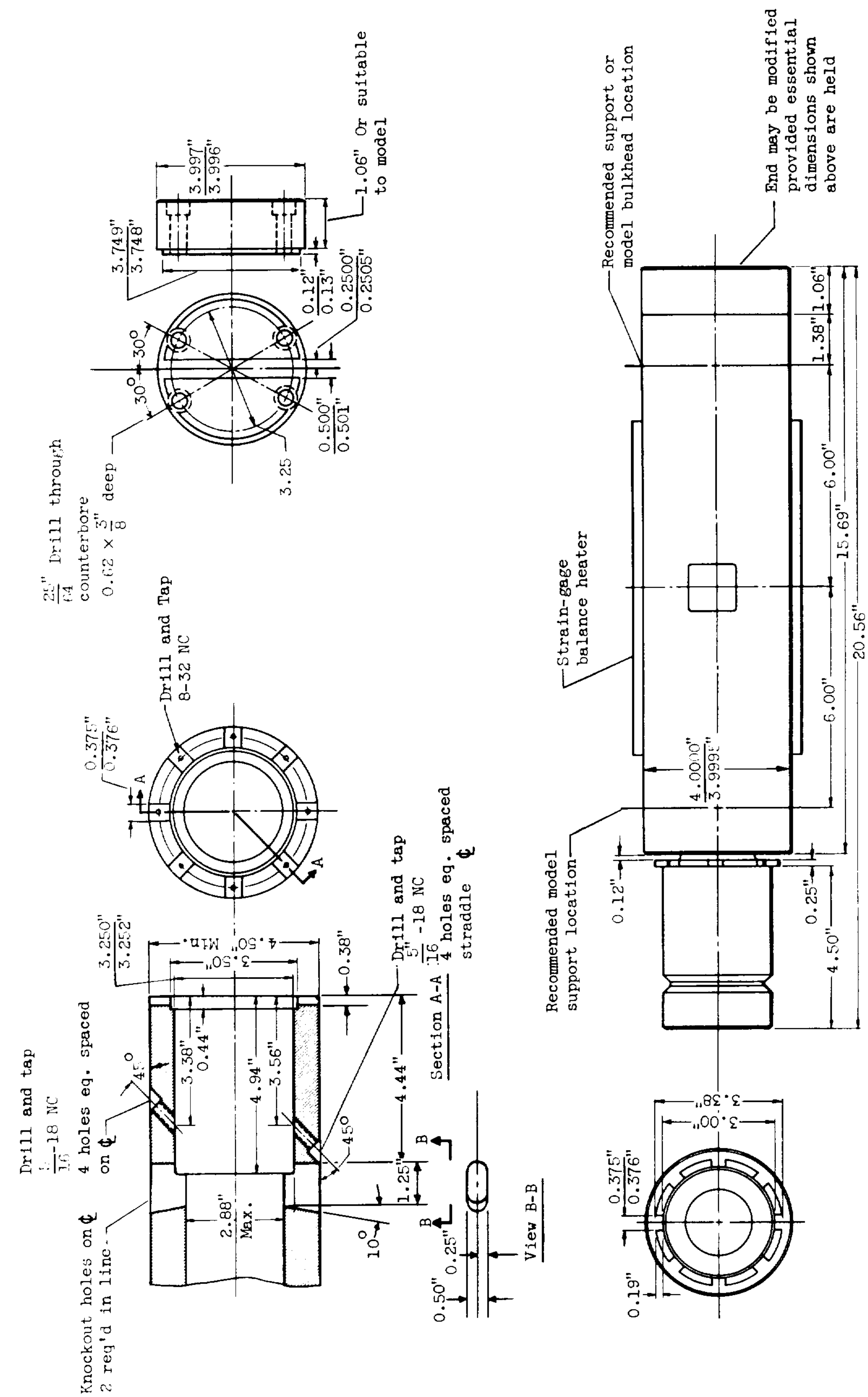


Figure 10. - 4-inch strain-gage balance, Lewis Unitary Plan Wind Tunnel.

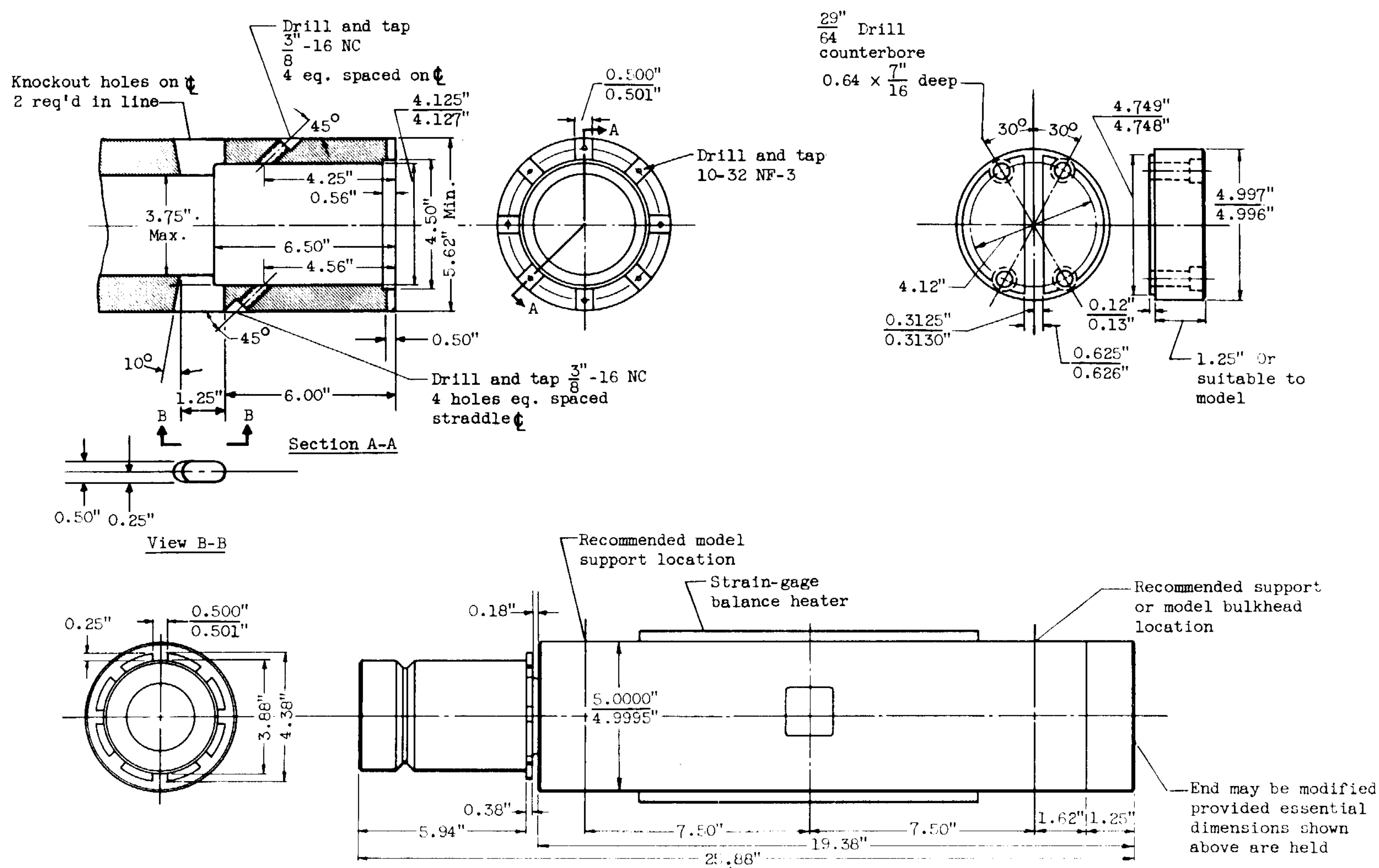


Figure 11. - 5-inch strain-gage balance, Lewis Unitary Plan Wind Tunnel.

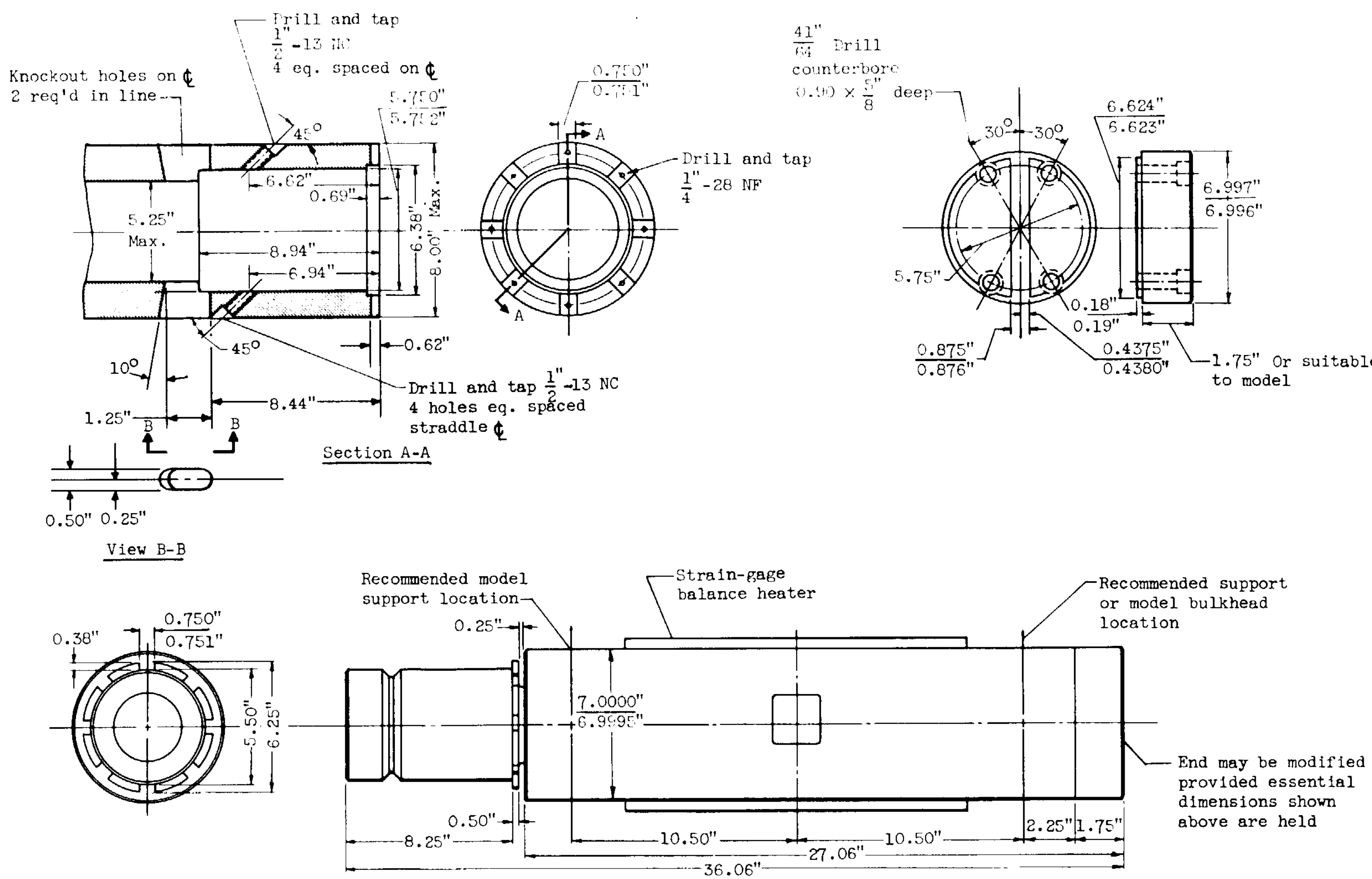


Figure 12. - 7-inch strain-gage balance, Lewis Unitary Plan Wind Tunnel.

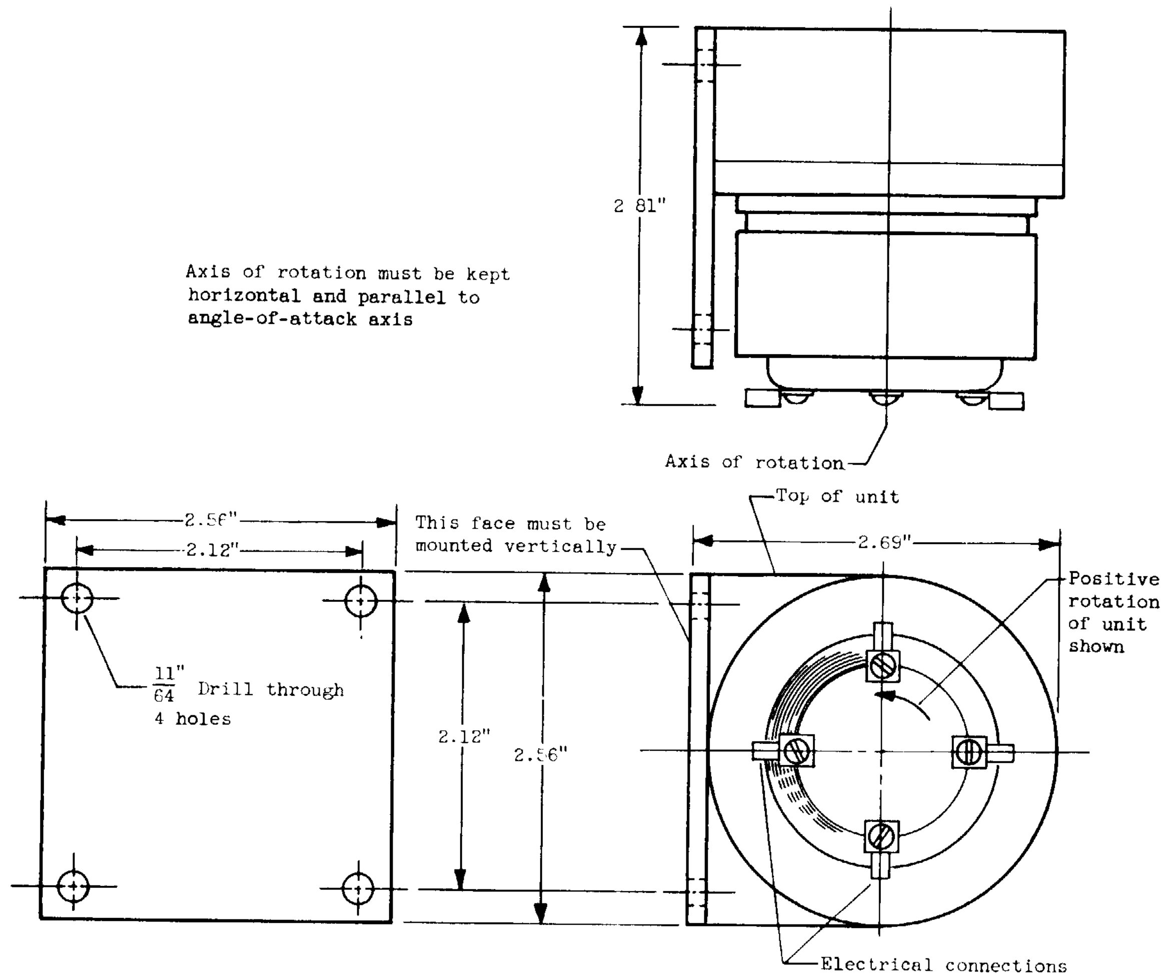


Figure 13. - Attitude indicator transmitter, Lewis Unitary Plan Wind Tunnel.

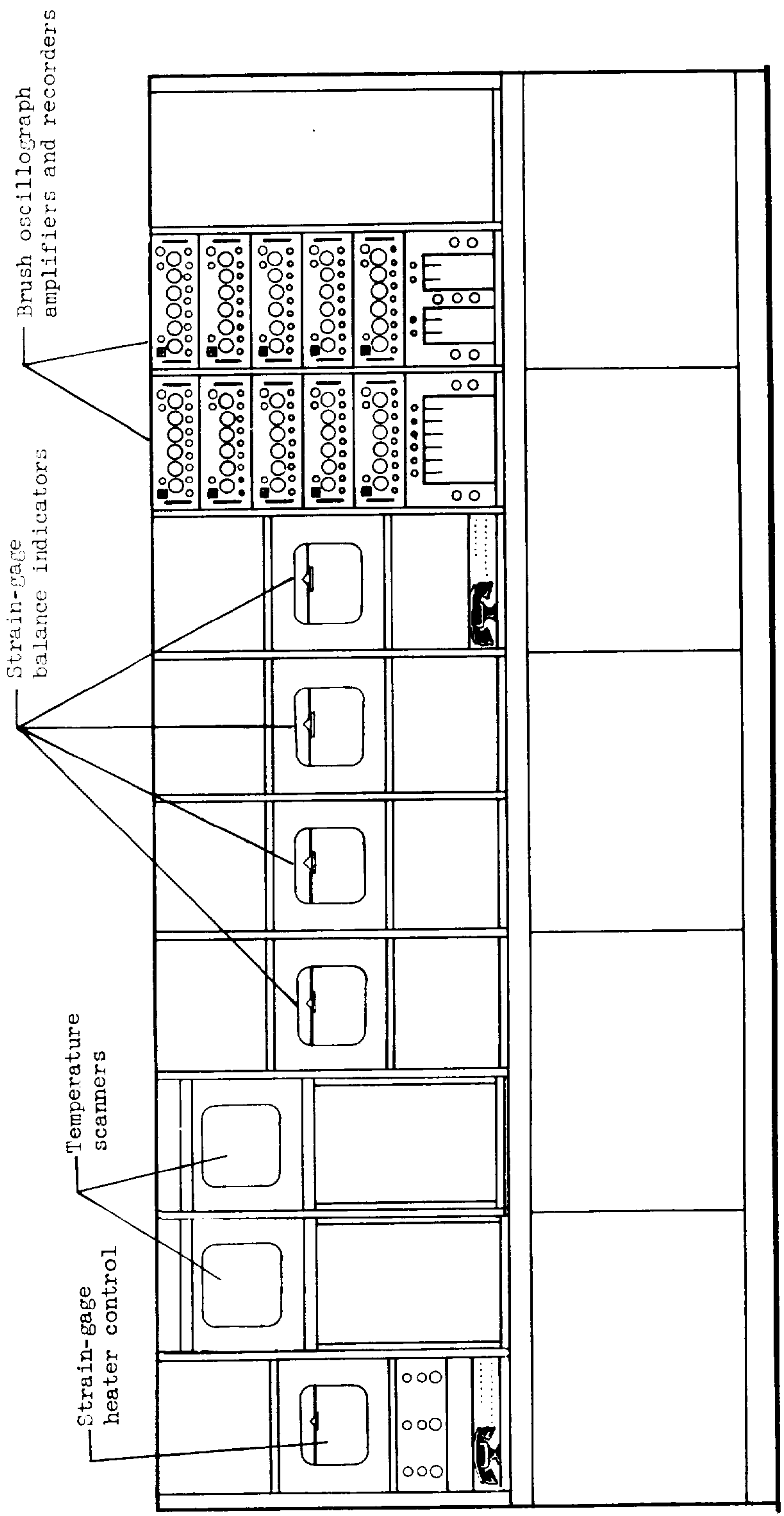


Figure 14.- East control panel, Lewis Unitary Plan Wind Tunnel.

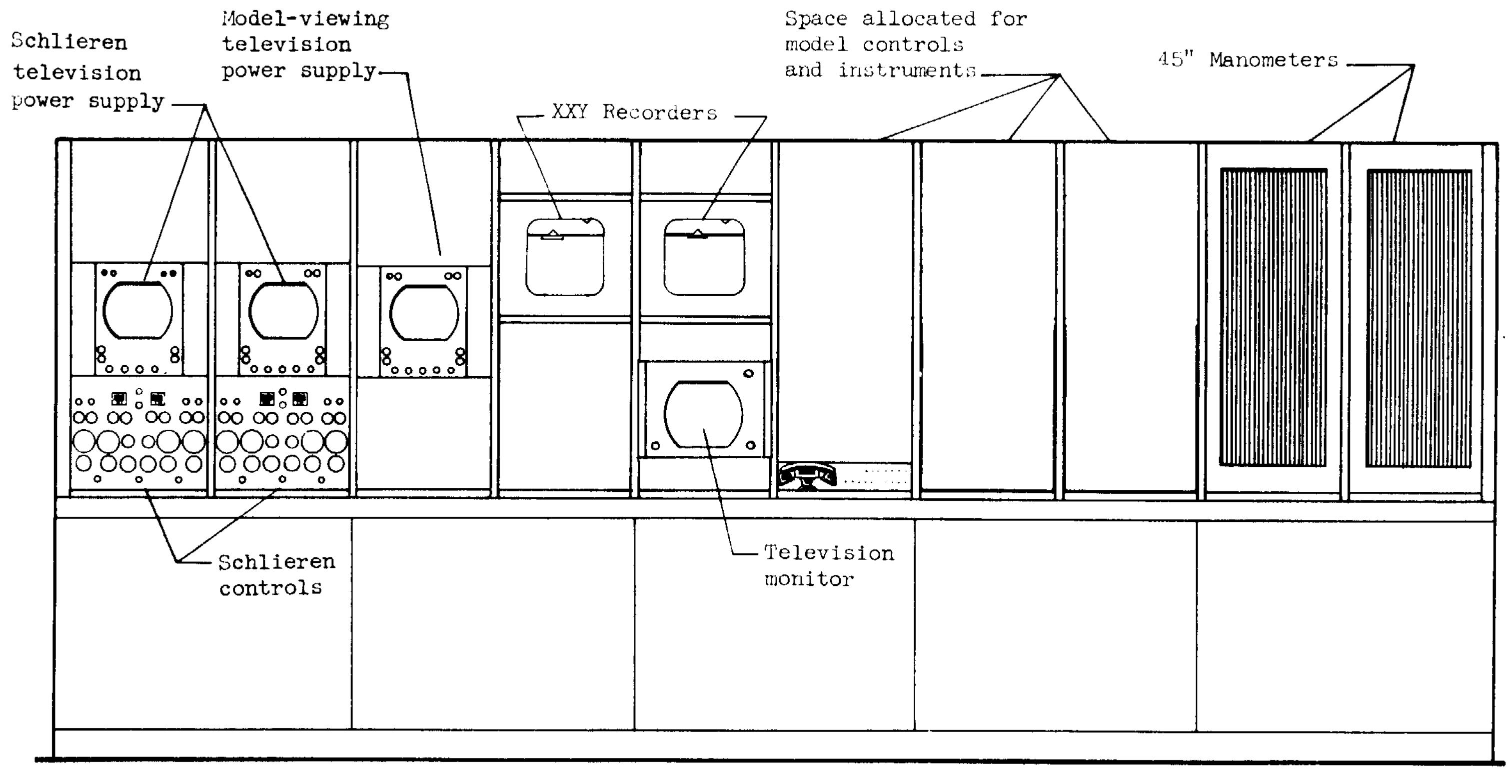
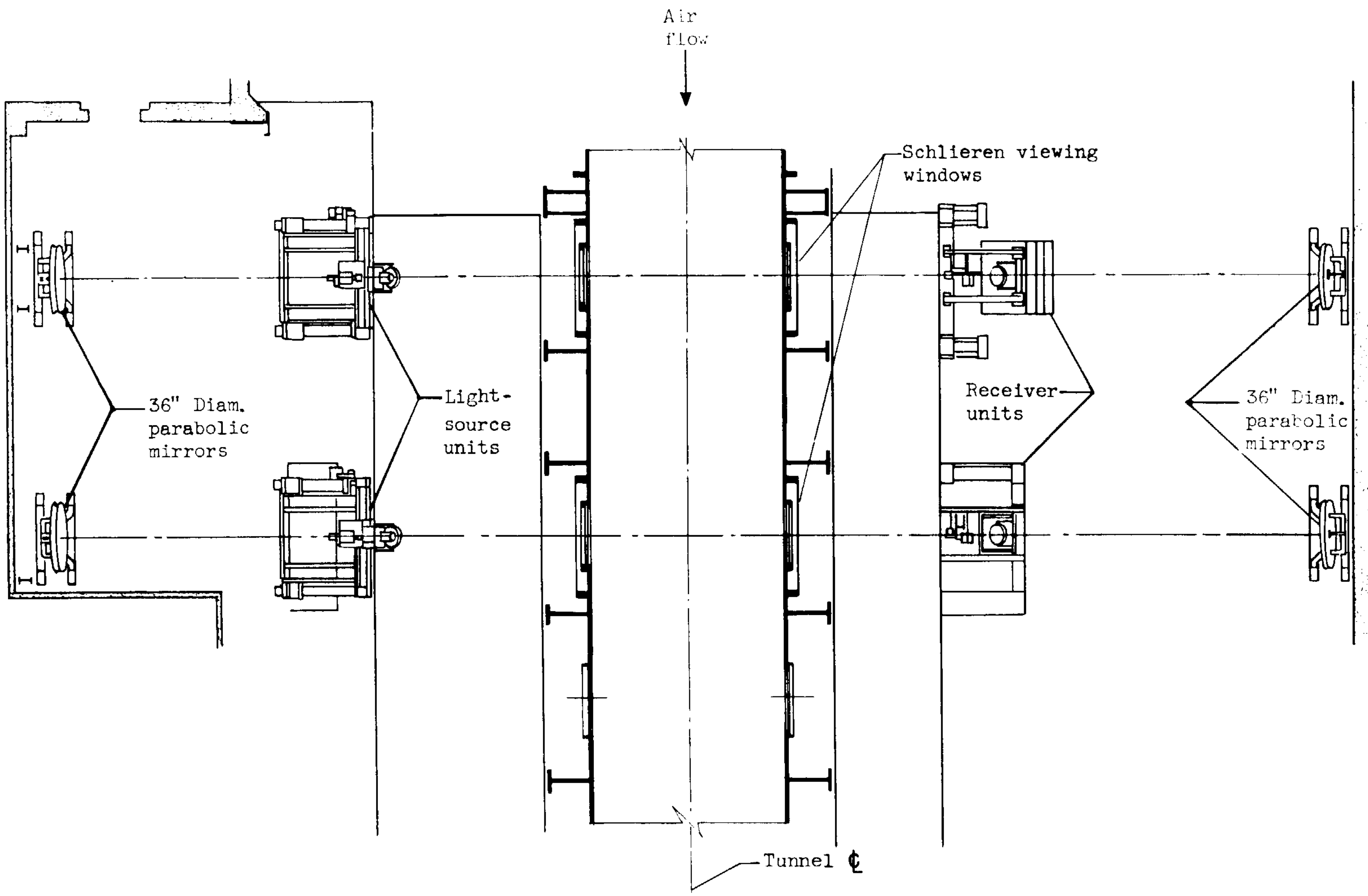
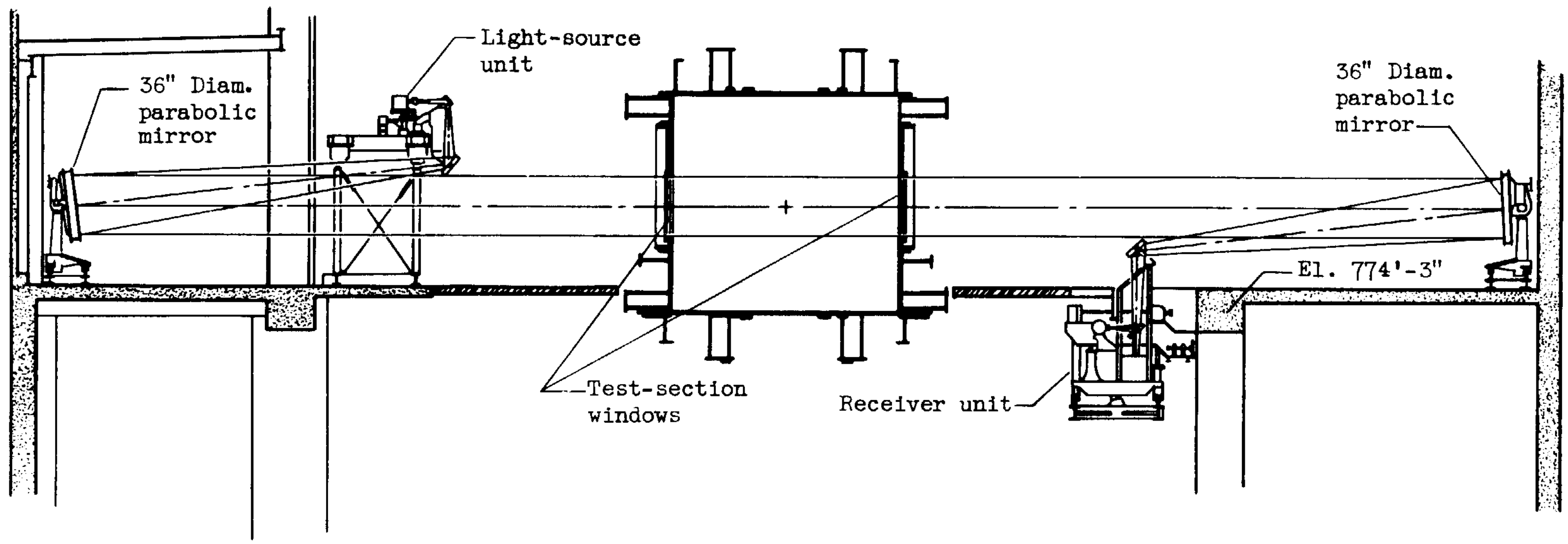


Figure 15. - West control panel, Lewis Unitary Plan Wind Tunnel.



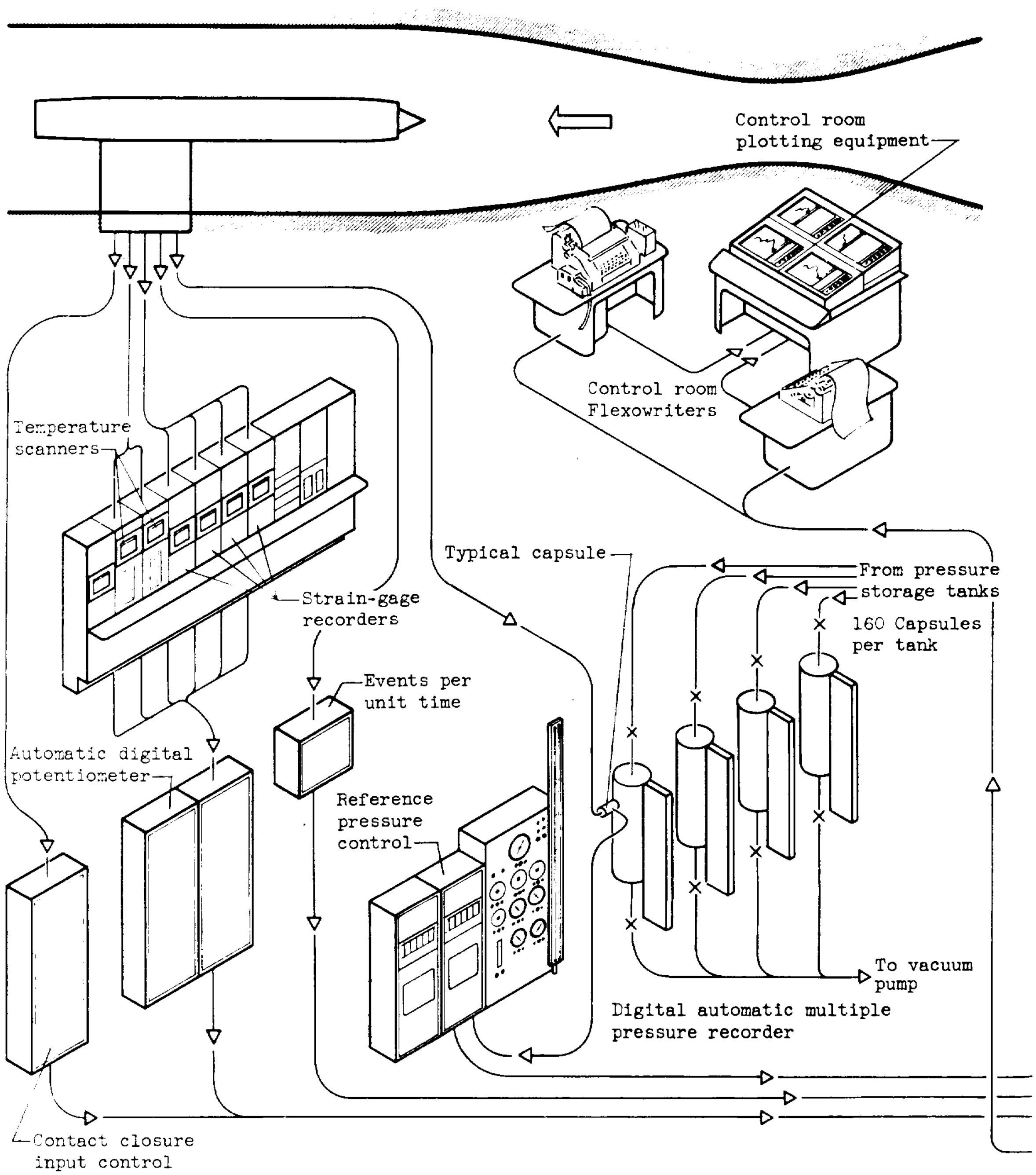
(a) Plan view.

Figure 16.- Schlieren system, Lewis Unitary Plan Wind Tunnel.



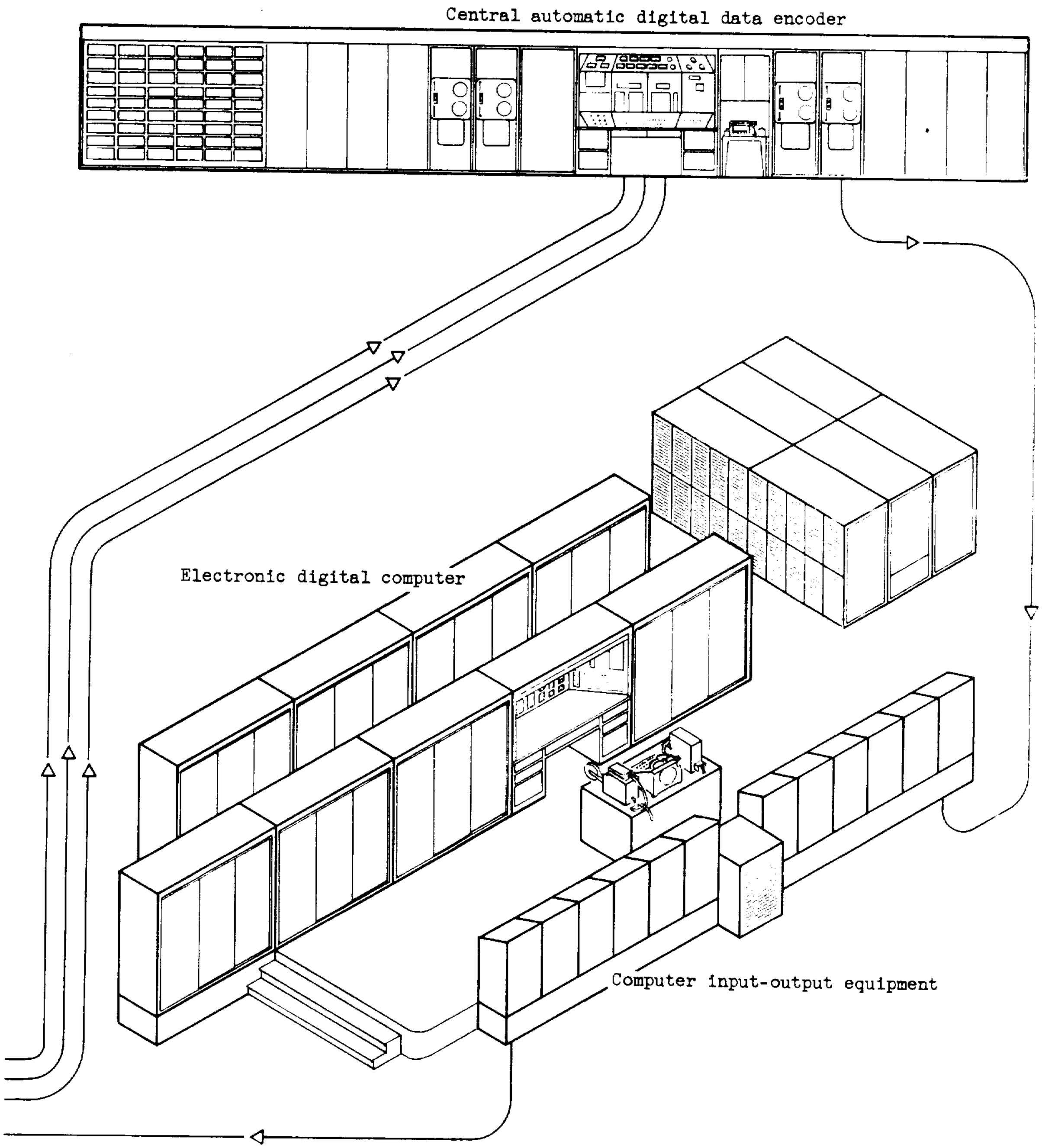
(b) Elevation view looking upstream.

Figure 16.- Concluded.



(a) Wind-tunnel equipment.

Figure 17. - Automatic data recording and processing system, Lewis Unitary Plan Wind Tunnel.



(b) Central computing equipment.

Figure 17. - Concluded.

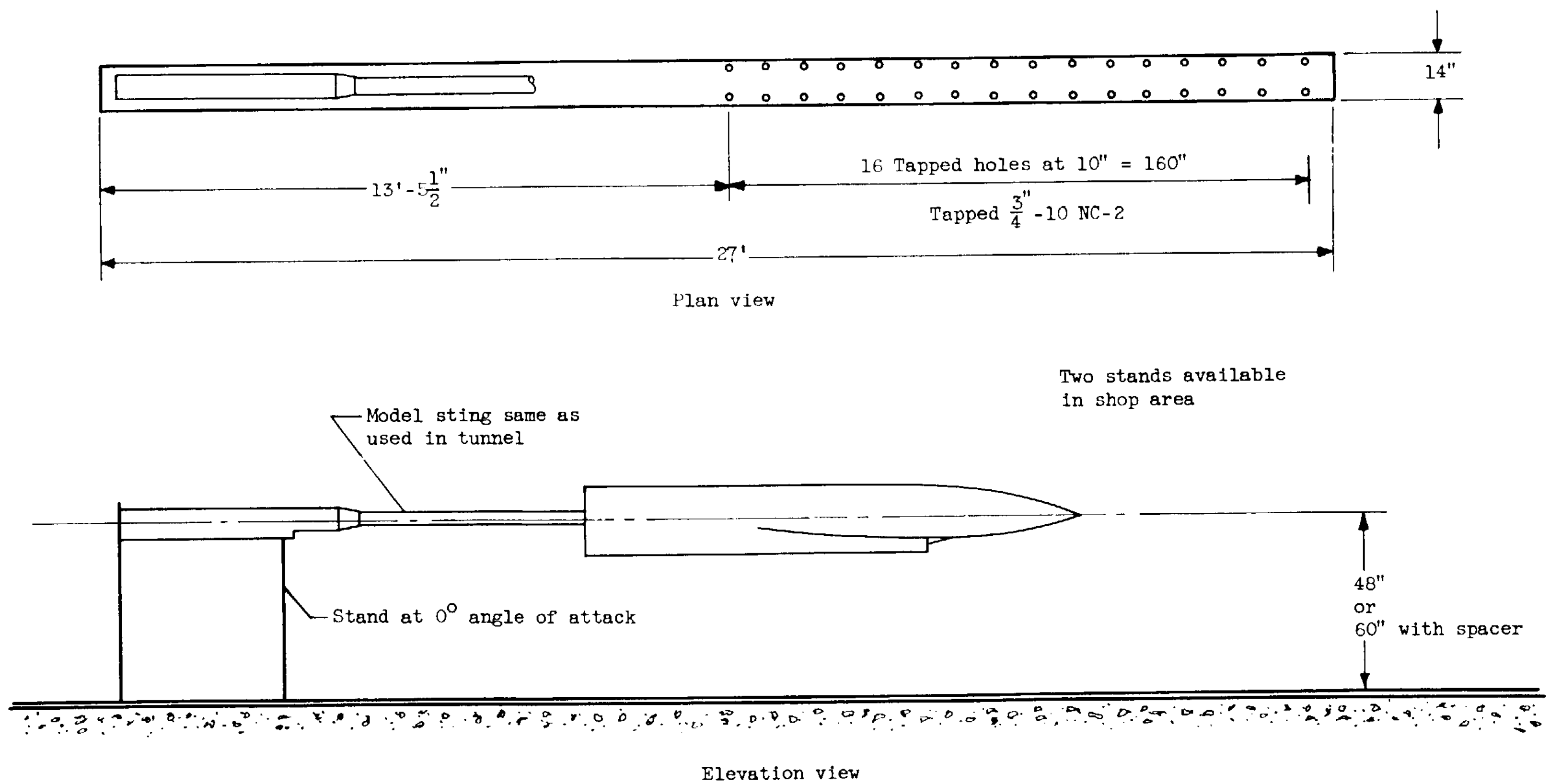


Figure 18. - Shop stand for sting-mounted models, Lewis Unitary Plan Wind Tunnel.

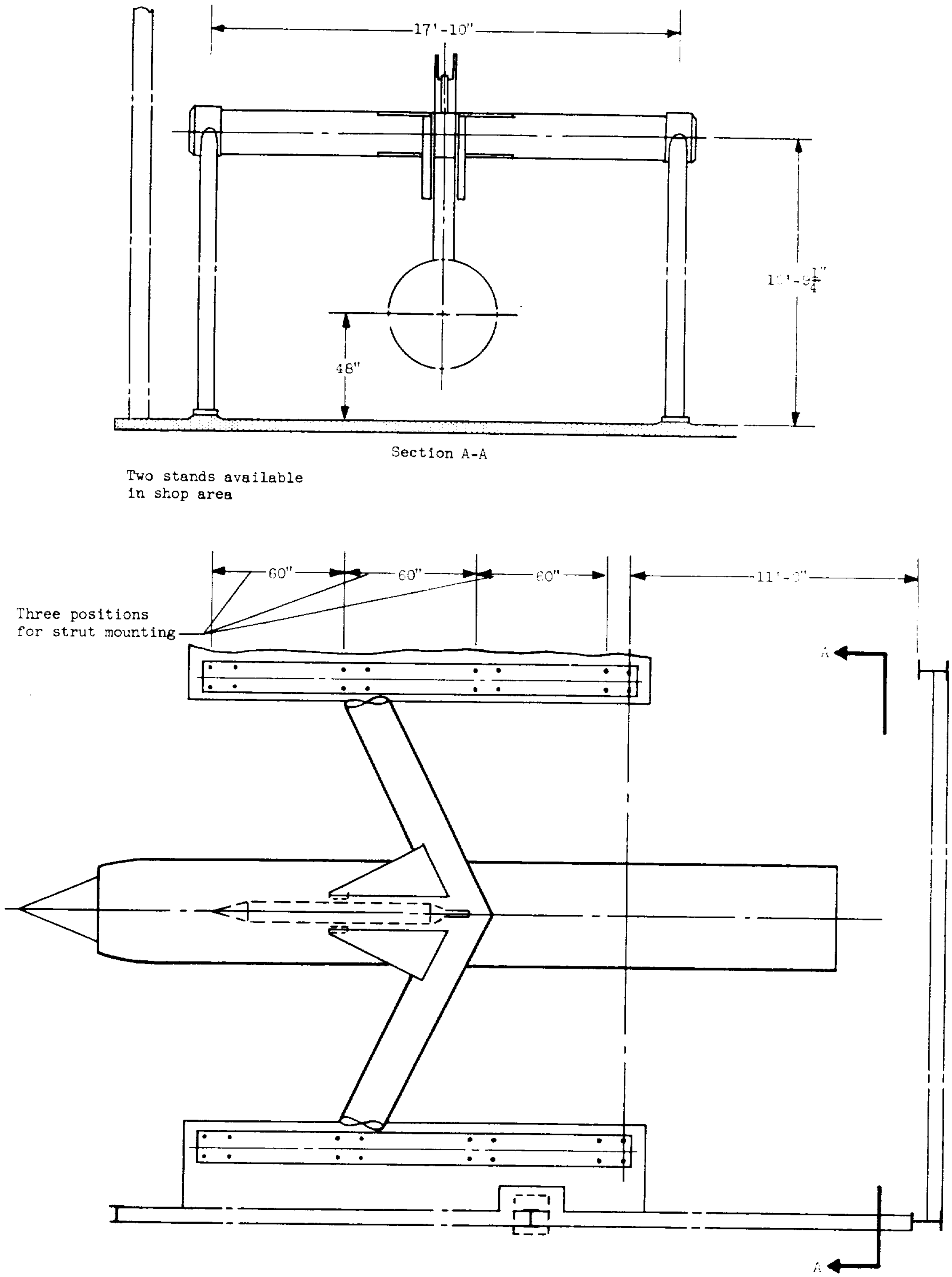


Figure 19. - Shop stand for suspended models, Lewis Unitary Plan Wind Tunnel.

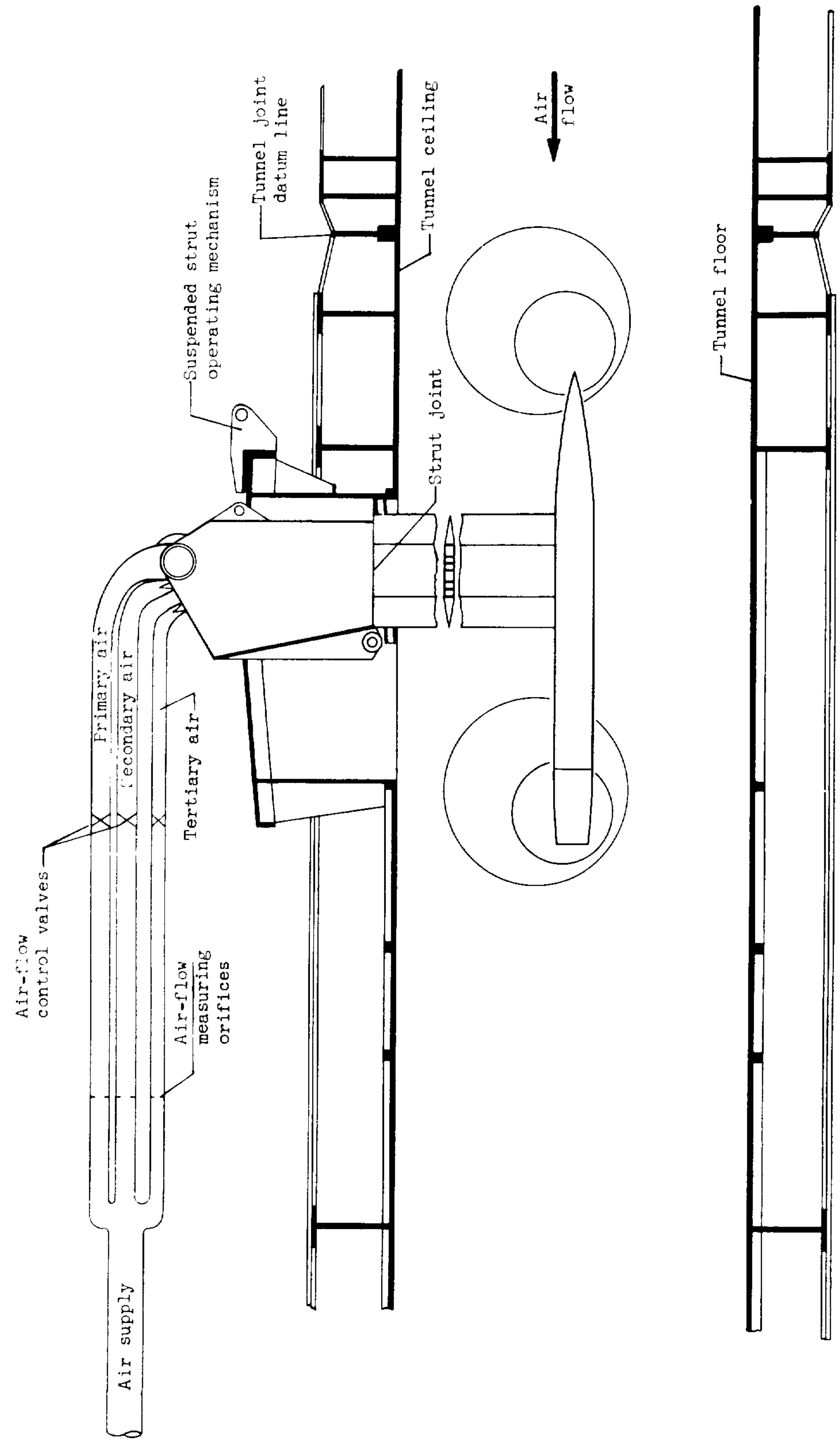


Figure 20.- Jet-effects model installation, Lewis Unitary Plan Wind Tunnel.

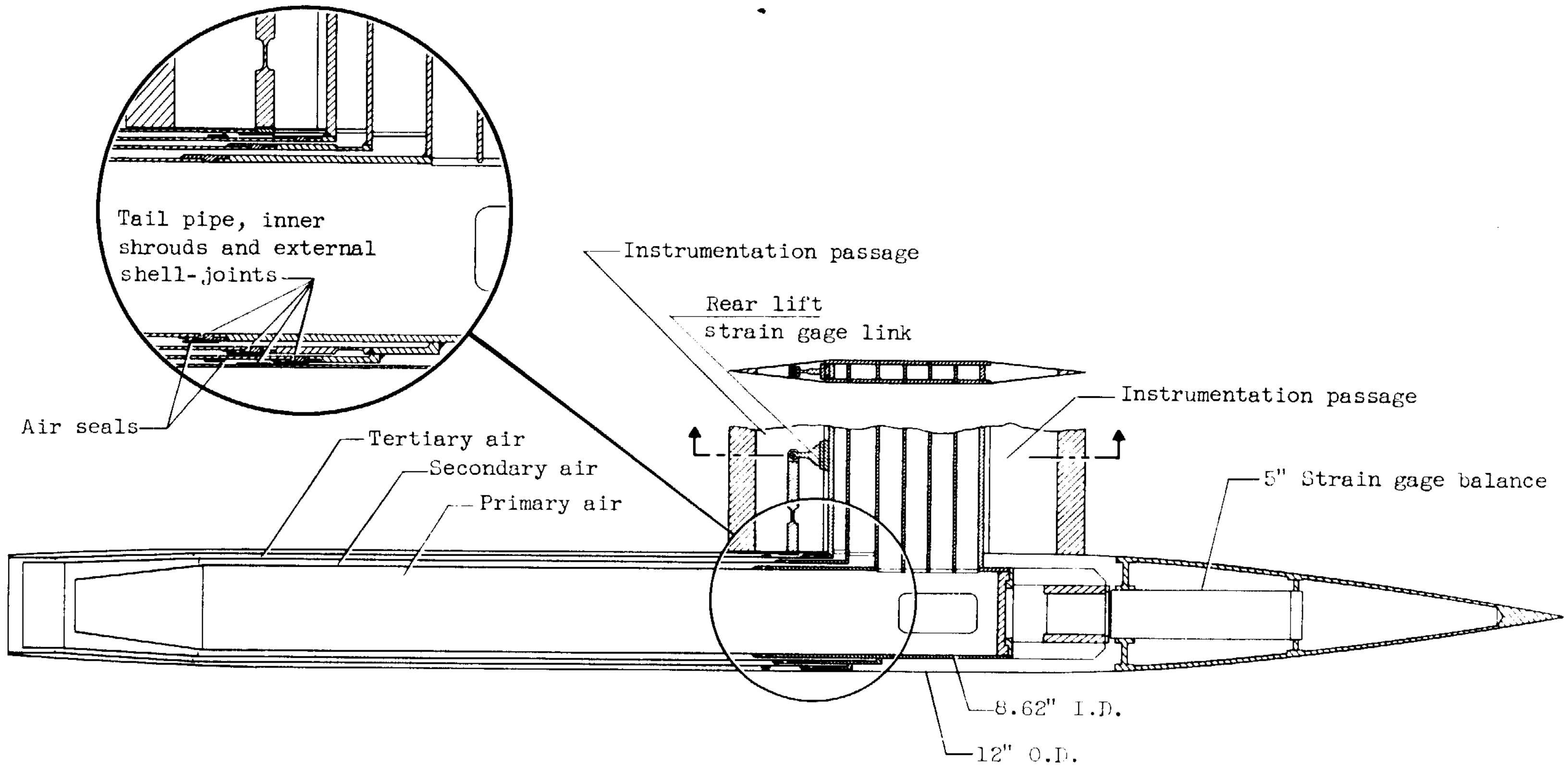
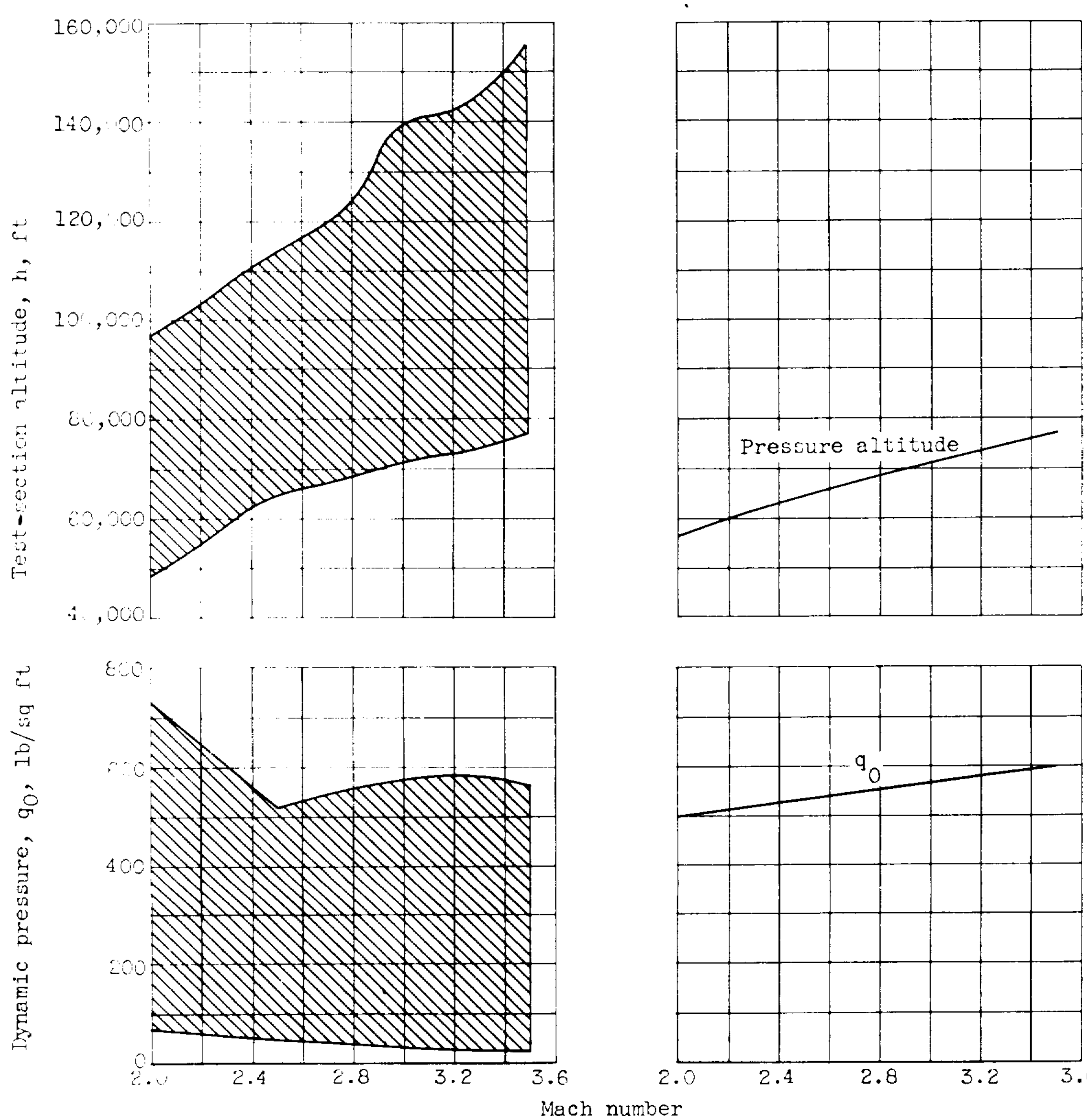
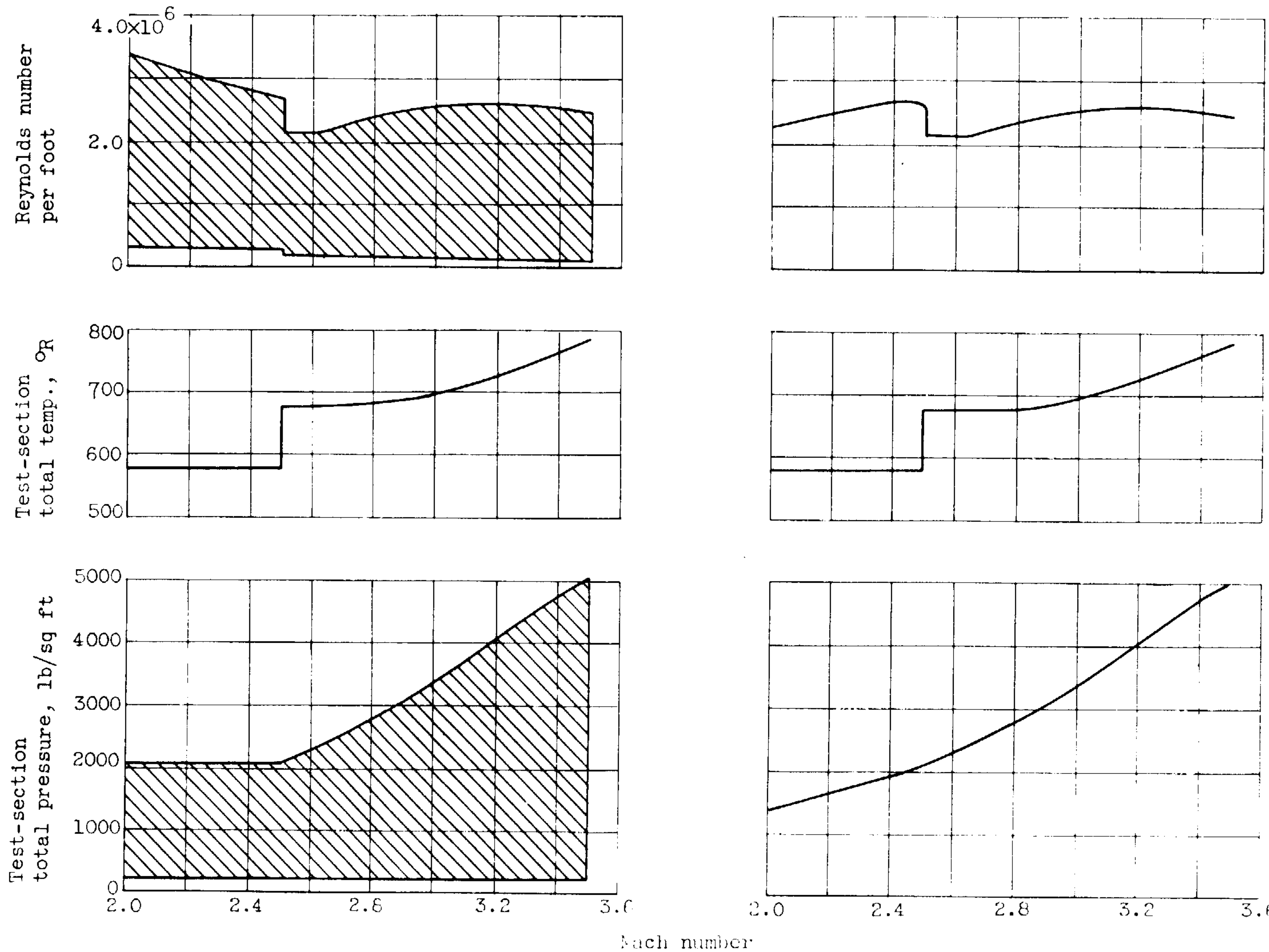


Figure 21. - Jet-effects model, Lewis Unitary Plan Wind Tunnel.



(a) Aerodynamic tests. (b) Propulsion tests.

Figure 22. - Estimated performance, Lewis Unitary Plan Wind Tunnel.



(a) Concluded.

(b) Concluded.

Figure 22. - Concluded.

THE LEWIS 8-BY-6 FOOT SUPERSONIC WIND TUNNEL

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NACA

130 (a)

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THE LEWIS 8-BY-6 FOOT SUPERSONIC WIND TUNNEL

GENERAL DESCRIPTION

The NACA Lewis 8- by 6-foot Supersonic Wind Tunnel is a continuous-operation non-return wind tunnel with a controlled Mach number range of from 2.1 to a lower limit determined by model blocking and shock reflection.

As illustrated in figure 1, the air first enters the alumina air dryer where the air has to pass through one of the eight alumina beds containing a total of 1200 tons of alumina. The air dryer absorbs approximately 1 ton of water per minute on a summer day with 67° F saturated air. A dewpoint of -40° F is maintained. The air dryer is reactivated after each run, which requires approximately nine hours. The air then enters the plenum chamber and the seven-stage axial-flow compressor. The compressor is driven by three electric motors totaling 87,000 horsepower. The compressor speed is controlled from 745 to 880 rpm. The maximum air flow is 2,000,000 cubic feet per minute, and the maximum compression ratio is 1.8. From the compressor the air passes through the flexible-wall nozzle, which can be varied while the tunnel is operating to control the test-section Mach number. The flexible nozzle is made of stainless steel and is 35 feet 6 inches long and 1 inch thick. The air then expands to supersonic flow in the stainless-steel test section; this section is 39 feet long, 8 feet high, and 6 feet wide. After leaving the test section, the air flows through the diffuser and the acoustical muffler and is exhausted to atmosphere. Both burning (propulsion) and nonburning (aerodynamic) models may be tested in this wind tunnel.

TEST SECTIONS

The 8- by 6-foot test section is made of 1-inch-thick stainless-steel plates. There is a personnel access door on one side of the test section and removable hatches on the top and bottom plates, as indicated in figures 2 and 3. These hatches cover openings provided for model struts and accessory mountings.

Models are installed through an access hatch in the tunnel diffuser downstream of the personnel door. Models are rolled under this hatch on dollies, hoisted into the tunnel, and wheeled into location to be mounted on struts or stings.

Available at the test section are a schlieren apparatus, periscopes, and all other instrumentation necessary for conducting a research test. The schlieren apparatus consists of two light sources, one receiving unit, and two 48-inch mirrors mounted on a lathe bed that allows for positioning of the mirrors. A diagram of the test section with no model installed is shown in figure 4. The centers of the $26\frac{1}{2}$-inch-diameter viewing windows may be rotated about a 16-inch-diameter circle for the best view of the particular model being tested. A periscope is also available for viewing engine tailpipes and flames.

MODEL SUPPORT SYSTEMS

Typical installation of a strut-mounted model in the test section is shown in figure 5. A sting-mounted model installation, using a strain-gage balance at the end of the sting, is shown in figure 6. Angle-of-attack ranges and sting and strut positions are indicated, as well as the position of the end of the sting in relation to the strut center line (2.5 in.). Openings are provided in the struts and stings for model instrumentation and wiring.

The strut has remote-controlled angle-of-attack drive capable of a ±10° angle. The maximum allowable loads of pivot are: horizontal shear, ±6000 pounds; vertical shear, ±6000 pounds; and moment, ±200,000 pound-inches.

The sting mount has remote-controlled angle of attack capable of +20° to -5°. The maximum allowable loads at the model-sting joint are: axial, ±3500 pounds; shear, ±8500 pounds; and moment, ±400,000 pound-inches.

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MODEL INFORMATION

DELIVERY: Models that are to be tested in the Lewis 8- by 6-foot Supersonic Wind Tunnel must be delivered to the Lewis Laboratory at least four weeks before the model is to be installed in the tunnel. Instrumentation junction panels and wiring can be installed at this time in preparation for tests.

MODEL SIZES: The variation with Mach number of maximum model frontal area permitting the start of supersonic flow in the tunnel is presented in figure 7. Since this curve represents the absolute maximum frontal area, the actual model frontal area must remain below this curve. This is especially important when large angles of attack are anticipated, because blockage is added.

MODEL STRENGTH: The maximum allowable stresses for the critical loading conditions shall not exceed one-fifth of the ultimate strength or one-third of the yield, whichever is least. In addition, for members loaded as columns, the Euler critical load shall be at least three times the applied load. The starting loads shall be assumed to be twice those resulting from the maximum steady-state dynamic pressure. The maximum steady-state dynamic pressure for the Lewis 8- by 6-foot Supersonic Wind Tunnel is 1200 pounds per square foot.

All auxiliary parts of the model that will be exposed to the airstream and are nominally at zero angle of attack shall be checked to at least $\pm 10^{\circ}$ angle of attack at the highest dynamic pressures anticipated in the tests. All models shall have materials to stand 300° F temperature.

PRESSURE-ORIFICE SPECIFICATIONS AND TUBING SIZES: All pressure orifices are to be of 0.065-inch-diameter fully annealed tubing of 0.009- to 0.012-inch wall. A minimum length of 18 inches shall be left on a rake made by the user. The connections from the rake tubing to tubing runs out of the model and the material needed are supplied and installed by the NACA Lewis Laboratory when the model is prepared for the tunnel.

SPECIAL CONSIDERATIONS FOR INLET MODEL INVESTIGATION: Model designs for inlet investigations shall simulate the full-scale configurations for sufficient distance to assure inlet and boundary-layer flows corresponding to the full-scale configuration. The inlet ducts shall duplicate the full-scale configuration to the compressor face, and aft of the compressor face the ducts shall simulate only to the extent that the design mass-flow ratio can be passed and metered with a choked movable plug. Auxiliary ducts, that is, boundary-layer and bypass ducts, shall be simulated to pass and meter design mass flow with a choked movable plug. A schematic layout of the simulated duct aft of the compressor face is shown in figure 8. The plug is driven by a screwjack actuator, and position indication is by a geared selsyn arrangement. The selsyn at the screwjack is geared to turn 37.5 turns per inch of travel. A selsyn in the control room is connected directly to a tenth revolution counter; thus, the resolution is 375 counts per inch of travel. Geared from the counter drive shaft is a ten-turn potentiometer that is connected to the automatic digital potentiometer, which is discussed in the section on AUTOMATIC RECORDING EQUIPMENT. This potentiometer gearing is such that the full plug travel is represented on the potentiometer as ten turns.

Provision shall be made for the installation of dynamic-pressure pickups in the ducts at locations where indications of instability (buzz) can be obtained. Dummy plates shall be provided to replace pressure-rake instrumentation that is to be removable. All rakes shall be made of fully annealed 0.065-inch stainless-steel tubing of 0.009- to 0.012-inch wall and shall be rigidly supported. All soldering on the rakes shall be silver solder. All details of rake and plug drives should be discussed with the tunnel staff before construction.

CONSIDERATIONS FOR EXIT STUDIES: The NACA Lewis Laboratory jet-effects model shown in figure 9 is trunnion-mounted in blank disks that replace the forward tunnel schlieren windows. The two wing struts have a thickness ratio of 6.08 and serve as ducts to get high-pressure air into the model. A flexible connection between the 8-inch-diameter high-pressure air line (described under AIR-SUPPLY SYSTEM) and the wing trunnion mount permits an angle-of-attack range of $\pm 8^{\circ}$.

The wings and centerbody assembly are grounded to the tunnel, while the external fuselage is supported by a balance system and rear support strain-gage links and side force bearings. The exit pipe assemblies show two different force connections; that is, both pipes on the balance or only the external pipe on the balance and the inner pipe connected to the centerbody. The rear chambers of both wings are connected to the air supply through a separate throttle and metering system, so that secondary air flow to the exit pipes may be controlled and measured up to 25 percent of the primary-nozzle flows.

The user may furnish tailpipes to conform to his configurations and use the rest of the model as exists, or change both the nose sections and tailpipes to conform to his particular configuration. It is possible that the user may want to furnish the whole model and attach to the wing trunnion mounts. However, a user should consult with the wind-tunnel staff before beginning design on a jet model configuration.

ELECTRICAL LEADS: Four types of electrical cables are used between the model and the control room. The "A" type cables are five conductors of number 10 wire and are used for power circuits (2 amps or more at 28 volts direct current or 5 amps or more at 120 volts alternating current). The "B" type cables are six conductors of number 20 wire and are used for low-level circuits such as pressure pickups, strain gages, etc. The "C" type cables are twelve conductors of number 16 wire and are used for control purposes (small motors, limit switches, selsyns, etc.). Each "C" cable is split into two six-conductor cables at the struts. The "D" type cables are single-conductor coaxial cables and only one pickup or strain-gage circuit is wired to each cable. Cables from the top and bottom of the tunnel go to a patch panel located under the tunnel, where they terminate in AN connectors and may be cross-connected to other cables that go to the control room and terminate on terminal strips for "A" and "C" cables and AN connectors for "B" and "D" cables. There are enough cables available between the tunnel and control room so that wiring for the future model can be done while a test is in progress.

THERMOCOUPLE LEADS: Wiring for thermocouples exists from the top strut and lower strut to the control room. Copper leads are paralleled with the alloy leads below the tunnel and are routed to the automatic digital potentiometer. Wiring for twenty-five iron-constantan thermocouples and fifteen chromel-alumel thermocouples is available at the upper strut. Wiring for fifteen iron-constantan thermocouples and twenty-five chromel-alumel thermocouples is available at the lower strut. The thermocouple wiring terminates in five 26-circuit Thermo Electric Co. type JBW-5 panels. All thermocouples from models are to be terminated in Thermo Electric Co. type 2PSS plugs.

INSTRUMENTATION AND DATA PROCESSING

BALANCES: Balances for the measurement of forces will be supplied by the NACA Lewis Laboratory. Three-component bearing-type strain-gage balances are available for sting-supported models. Dimensions and installation details are shown in figure 10. These balances are self-contained internal strain-gage balances. Ball and roller bearings are used to isolate the components. Actual measurement of the forces is made by Baldwin SR-4 strain gages mounted on cantilever beams. The three components measured are axial force, front normal force, and rear normal force. The balances contain interchangeable links, so there is a wide selection of capacities available. The links available for the 4-inch balance are listed in the following table:

Axial force, lb	Front normal force, lb	Rear normal force, lb	Distance between front normal and rear normal links, in.
100	100	100	12
200	200	200	
300	400	400	
500	600	600	
800	1000	1000	
1200	1500	1500	
1800	2500	2500	

The links will take momentary overloads up to 200 percent of their capacity without damage. Continual overloads of this magnitude may rupture the SR-4 strain gages. The steel in the links will take 500 percent of the rated capacity before failure.

When it is necessary to maintain close alinement between the model and the sting at the rear of a large model, an external rear normal link is sometimes used in place of the one within the balance. This arrangement also increases the pitching-moment capacity of the balance system by increasing the distance between the front normal and rear normal links. The external link is usually identical to the links within the balance. Additional bearings are also required at the rear. Details of the mounting of the rear link and bearings are engineered for each model. NACA Lewis Laboratory will furnish the link.

Equipment is available in the shop area to check out and calibrate the balances. It is possible to apply any combination of loads to the balances. Loads are applied by hand-operated screwjacks. A strain-gage link is used for measuring the load applied. Equipment is also available for checking the calibrating strain-gage links against dead weights. After the balance is installed in the model, the same type of screwjack assembly is used for applying loads to the complete model both in the shop and in the tunnel. A heater, provided by NACA Lewis Laboratory, is installed around the balance to maintain the balance at a constant temperature during the tunnel run to eliminate changes in calibration and zero shift due to temperature variations.

Four automatic-balancing potentiometers with associated power supplies and controls are available in the control room for reading and recording the output of the strain-gage balances. Four more channels are available in the shop area on a rolling console for preliminary checkout and calibration.

CONTROL-ROOM INSTRUMENTATION: In the control room there are instruments for observing model and tunnel performance during the tunnel operation. There are two banks of sixty-tube manometers; the first is used to monitor tunnel conditions and the second is for model pressure distribution.

Four Leeds and Northrup Speed-O-Max indicators are used to measure forces on the model picked up by strain-gage balances. Automatic range extenders are used to give an expanded scale for better readability.

The strain-gage balances can be switched to Brush pen recorders for the recording of transient loads.

For the electrical recording of pressure fluctuations of transients, a Century light-beam recording oscillograph is available with twelve channels of carrier amplifiers. This equipment is used with pressure transducers such as Statham, Consolidated, Wiancko, or others. The recorded signals can be monitored with either cathode-ray oscilloscopes or the Brush pen recorder.

To measure the attitude of the model with respect to the horizontal, an attitude indicator is available. The pickup unit is mounted in the model and will fit in a space 4 inches in diameter and 4 inches long. The indicator unit has a dial reading in degrees.

For models having long aluminum ducts where the elongation of the duct with temperature can cause errors in plug area, a Shaevitz transformer is used with the coil fastened to the sting or other support and the core mounted from the duct. The indicator is manually adjusted and reads directly in thousandths of an inch through the use of a standard micrometer barrel.

An X-Y recorder is used to record the ratio of two pressures on the Y-axis and plug position on the X-axis. This device used Statham pressure transducers to sense the desired pressures.

Temperatures are measured on Brown temperature potentiometers. Selector switches are used, making available a total of fifty iron-constantan circuits and twenty-eight chromel-alumel circuits.

For the control of movable plugs, ramps, and other devices, 24-volt direct-current motors are usually used. Position indication is accomplished by the use of 120-volt 60-cycle and 120-volt 400-cycle selsyns driving counters. The 400-cycle selsyns are used where space is limited.

AUTOMATIC RECORDING EQUIPMENT: The Lewis Laboratory has a system known as the Central Automatic Digital Data Encoder (CADDE) which is used by five of the laboratory's major test facilities to record digital readings from transducers of pressure, voltage, events per unit time, and mechanical position. A diagram of this system is shown in figure 11. The information is recorded on magnetic tape as four binary coded decimal digits with four additional characters for identification and computation instruction. The magnetic tape is the permanent record of the raw data. It is transferred from the recorder to a magnetic-tape computer for processing at the completion of the run.

Digital automatic multiple pressure recorder (DAMPR): The DAMPR system pictured schematically in figure 11 consists of two tanks with one hundred and sixty capsules mounted on each tank. The capsule, which is the primary sensing element of the pressure-measuring system, breaks an electric circuit when the pressures on either side of a diaphragm are equal within 0.01 inch of mercury. The tanks are evacuated to about 0.1 inch of mercury and then sealed off. When a reading is taken, pressurized air enters the tanks through a choked orifice. The time from the start of the pressure rise until the tank and model pressures are equal is measured by counting pulses generated by an oscillator in CADDE. When the tank pressure equals the model pressure, the circuit between the oscillator and counter is opened by the capsule. The number in the counter is proportional to the time required for the tank and model pressures to be equalized. This number is stored in a three-hundred-channel magnetic core memory for read-out to the magnetic-tape handler and computer at the completion of the pressure scan.

The scan time (i.e., the time required for the pressure to rise to its maximum) is ten seconds, and the repetition rate is once per minute. The oscillator generates approximately 1000 pulses per second, so that the resolution of the pressure-measuring system is equal to 0.0001 of the upper pressure limit for the tank. The two tanks can have any pressure range up to 20,000 pounds per square foot.

The three hundred copper pressure lines from the tunnel are terminated on a patch panel by the DAMPR tanks. The input to two hundred and eighty-eight capsules is also brought out on this panel, so that any model tube can be jumpered to any capsule. The remaining thirty-two capsules are used for checking and to determine the slope and origin of the pressure-time line by applying known pressures to the capsules.

Automatic digital potentiometer (ADP): The ADP is a self-balancing multichannel millivolt meter with a digital read-out. It contains one balancing unit with a range of -2 to 38 millivolts. The potentiometer indicates a voltage as a percent of the range. The potentiometer balances and reads out directly on magnetic tape at the rate of 1.5 channels per second during the scan time of the DAMPR tanks. Therefore, 15 voltages can be measured during this ten seconds without slowing down the recording process. The instrument can read up to 50 voltages but will delay the transfer of the memory data to the tape handler if there are more than fifteen inputs.

The input switch gear for the balancing units can switch thermocouple cold junctions (100° F) of I.C. or C.A. in series with the input voltage on any channel. A remote compensation thermocouple system is used for thermocouple inputs.

Any type of voltage divider or strain-gage device having an impedance of less than 500 ohms can be measured with the ADP. A 38-millivolt power supply calibrated against the ADP standard cell is available for use with voltage-divider networks such as the retransmitting slide wires on the Leeds and Northrup potentiometers located in the control room.

Events per unit time (EPUT): Any instrument that generates pulses at a rate proportional to the input signal can have these pulses counted in the CADDE memory. By feeding the pulses through a ten-second time gate, the number of events occurring in a known time interval can be recorded and sent to the computer. Output of a tachometer or fuel flowmeter could be measured in this way. The total number of counts cannot exceed 100,000, and the counting rate cannot be greater than 20,000 counts per second. When more than 100,000 counts are generated in ten seconds, the length of time required to reach 100,000 counts is then recorded.

Contact closure devices: There are sixteen data bits to each binary coded decimal work recorded on tape and sent to the computer. A bit is present in a data word if there is a ground on the input to the shift register at the time it is loaded. The shift register is an electronic unit in which all numbers are assembled immediately before being recorded on a magnetic tape. A switching device located in the tunnel control room makes it possible to read up to twenty-five channels of information consisting of the presence or absence of a ground on any combination of the sixteen data bits.

Analog to digital converters are available to count shaft rotations of devices in the model or in the control room. These converters have sixteen wires on which combinations of grounds appear to represent numbers up to 10,000 with an uncertainty of one part. These converters also have a four-decimal visual indication of their position. They can be used with synchromotors to indicate positions of mechanical parts in the models.

Other contact closure devices, such as rotary switches, stepping switches, or toggle switches, can be used to put information into CADDE. This information can be data, calibration constants, or computer instructions.

The computer: The magnetic tape from CADDE is processed with a modified IBM 604 electronic calculator. The machine is capable of converting raw data from the tape to physical quantities using appropriate calibration coefficients. It can also calculate averages and ratios of the converted data. Calculated data are punched on IBM cards for tabulation. Additional calculations can be made on subsequent passes through other IBM equipment. Request for calculations must be received by the Mechanized Computing and Analysis Branch of the Lewis Laboratory at least three weeks before the test is to be run in the tunnel.

FACILITIES PROVIDED TO USERS

Each model is assigned a 15- by 25-foot area in the shop with four work benches and two sets of cabinets with storage shelves. These areas are served by a 2-ton crane, and carts are available for transporting all types of models about the shop or into the tunnel test section.

The shop area includes two T-slot bedplates with stands for assembling, instrumenting, and balance-calibrating sting-mounted models. Two stands are available, one for 0° and one for 6° angle of attack. Services available at each stand are a 125-pound air supply, vacuum, and 115-volt alternating-current power. In addition, there is a portable power supply consisting of 115 volts alternating current, 60 cycles; 115 volts alternating current, 400 cycles; 28 volts direct current; and an ohmmeter for checking grounds and short circuits. There is also a hanger for strut-mounted models with the previously mentioned services available.

A tool crib is located in the shop area supplying conventional shop tools and small hardware. Three drill presses, two tool grinders, a Do-All bandsaw, a power hacksaw, two metal-working lathes, and a milling machine are available. Any tools not in the tool crib may be obtained at the laboratory machine shop.

For sheet-metal work, there is a small roller, a bending brake, and two metal shears. Two gas-welding outfits, one arc welder, one heliarc welder, and a small spot welder are included in the fabrication equipment in the shop.

Lockers are provided for mechanics who maintain the model, and office space is provided for engineers.

AIR-SUPPLY SYSTEM: In addition to the normal service air supply for hand power tools, there is an 8-inch-diameter air line that supplies air for model purposes (i.e., exit studies).

Dry air is available at flows up to 18 pounds per second at a pressure of 60 psig and a dewpoint of -40° F. Operating time based on saturated air at 100 psi at 90° F entering the high-pressure activated alumina dryer is four hours at an average flow of 10 pounds per second.

FUEL SYSTEM: For propulsion tests of burning models, a fuel system is available to deliver liquid fuels such as aviation gasoline, alcohol, JP-4, etc., to the test section. The fuel is stored in two 2500-gallon tanks; therefore, two types of fuel may be used in several combinations. If a pilot burner is installed in a model such as the type used in a ram jet, pilot fuel flow up to 250 pounds per hour is available, while the main burner(s) may use up to 7920 pounds of fuel per hour. The pilot burner may operate on one type of fuel, while the main burner may use another type; or both may use the same fuel. In operating any type of propulsion system, the fuel may be changed to another type during testing by the proper manipulation of valves in the fuel building.

All the pumping and metering of the fuel is done in a separate fuel building, and the fuel is piped to the models in the test section. Fuel-flow rates are measured by rotameters, which are read in the fuel building and also read and automatically tabulated by Potter remote-reading flowmeters in the control room. These flow rates are listed in the following table, along with the fuel-pressure ranges:

	Fuel-flow range (rotameter), lb/hr	Fuel-flow range (Potter), lb/hr	Fuel-pressure range, psig
Pilot fuel	30-250		40-300
Main fuel	44-450 300-2500 1300-8000	250-2500 360-4320 540-7200	40-500

Control of main fuel is accomplished from the control room by the Annin Company air-operated valves, which are used as throttles. The pilot fuel does not have a remotely operated throttle; however, all fuel-pump pressures are regulated at the fuel building through the ranges tabulated. The main fuel line divides into two lines, each line being controlled by a throttle. A two-burner combination may be used, or a wide range of control is available if a single burner is used.

OPERATING CHARACTERISTICS AND POWER COST ESTIMATING

OPERATING CHARACTERISTICS: Operating time (condensation free flow), which is limited by the capacity of the air dryer, varies from about one hour on a hot summer day to over ten hours in cold winter weather. As the air passes through the air dryer and the moisture in the air is adsorbed by the activated alumina, heat is released which raises the temperature of the air before it enters the compressor plenum chamber. This temperature rise is proportional to the amount of water vapor in the air (specific humidity). Figure 12 shows how the ranges of tunnel total temperature and Reynolds number vary between winter and summer.

The tunnel total pressure, pressure altitude, and dynamic pressure are only slightly affected by the seasons; average values are shown in figure 13.

The test section and flexible-wall-nozzle portions of the tunnel are surrounded by airtight housings that are lowered in pressure during tunnel operation to decrease pressure loading on the nozzle and to balance the pressure across the model strut and support openings.

The available operating time for the tunnel is from 10:00 p.m. to 7:00 a.m. (dry air permitting) Monday through Friday.

POWER COST ESTIMATES: The data presented herein are for the purpose of estimating the costs for electrical power necessary for a particular test program in the Lewis 8- by 6-foot Supersonic Wind Tunnel. Based on the anticipated monthly consumption of the Lewis Laboratory during the fiscal year 1956, the average rate per kilowatt hour is expected to be between 8 and 9 mils.

The power required for the drive system is 36,000 kilowatts per hour at Mach 1.5 and 64,000 kilowatts per hour at Mach 2.0. The power required at intermediate speeds is proportioned between these limits. In addition, 2500 kilowatts per hour should be added for drive auxiliaries, and 8000 kilowatt hours of electrical energy are required per day of operation to reactivate the air dryer.

INFORMATION TO BE SUPPLIED BY THE USER

The user shall furnish the following information as soon as possible after the tests have been requested:

I. Model Details and Stress Analysis

A. DRAWINGS OF MODEL: Two complete sets of drawings of the model providing the following data pertinent to the model:
1. All configurations to be tested
2. Weights and center-of-gravity location
3. Materials employed in fabrication
4. Heat treatments
5. Types of bolts, screws, and other fasteners
6. Weld dimensions
7. Special methods of adhesive bonding
8. Location and identification of pressure rakes, probes, and orifices

B. DRAWINGS OR SKETCHES OF MODEL INSTALLATION: Drawings or sketches of model installation in the test section showing location and position in schlieren windows.

C. TEMPLATES: The user shall be prepared to provide templates of all critical surface contours (such as body and duct contours). A surface shall be considered critical if deviations from the prescribed ordinates would influence the test results. The number of templates to be provided is not specified, but should be sufficient to establish the conformation of the surface with the desired ordinates.

D. DIAGRAMS: Wiring diagrams of any internal electrical equipment the user furnishes in the model.

II. Test Program

A. ITEMS: The proposed test program should include the following items:

1. List of the data desired: e.g., forces, pressure, mass-flow measurements, pressure distribution, etc.
2. Tentative schedule of tests indicating model configurations, tunnel operating conditions, controls, increments, and ranges of variable parameters and data to be taken at each condition.

III. Data Analysis Information

A. MODEL AREAS AND DIMENSIONS: All areas and model dimensions required for computations.

B. PLOTTED RESULTS: Desired form of results for plotting.

C. COEFFICIENTS AND LOADS: Desired force and moment coefficient accuracies.

D. SPECIAL DATA: Schedule of any special data required such as balance calibration, probe calibrations, etc.

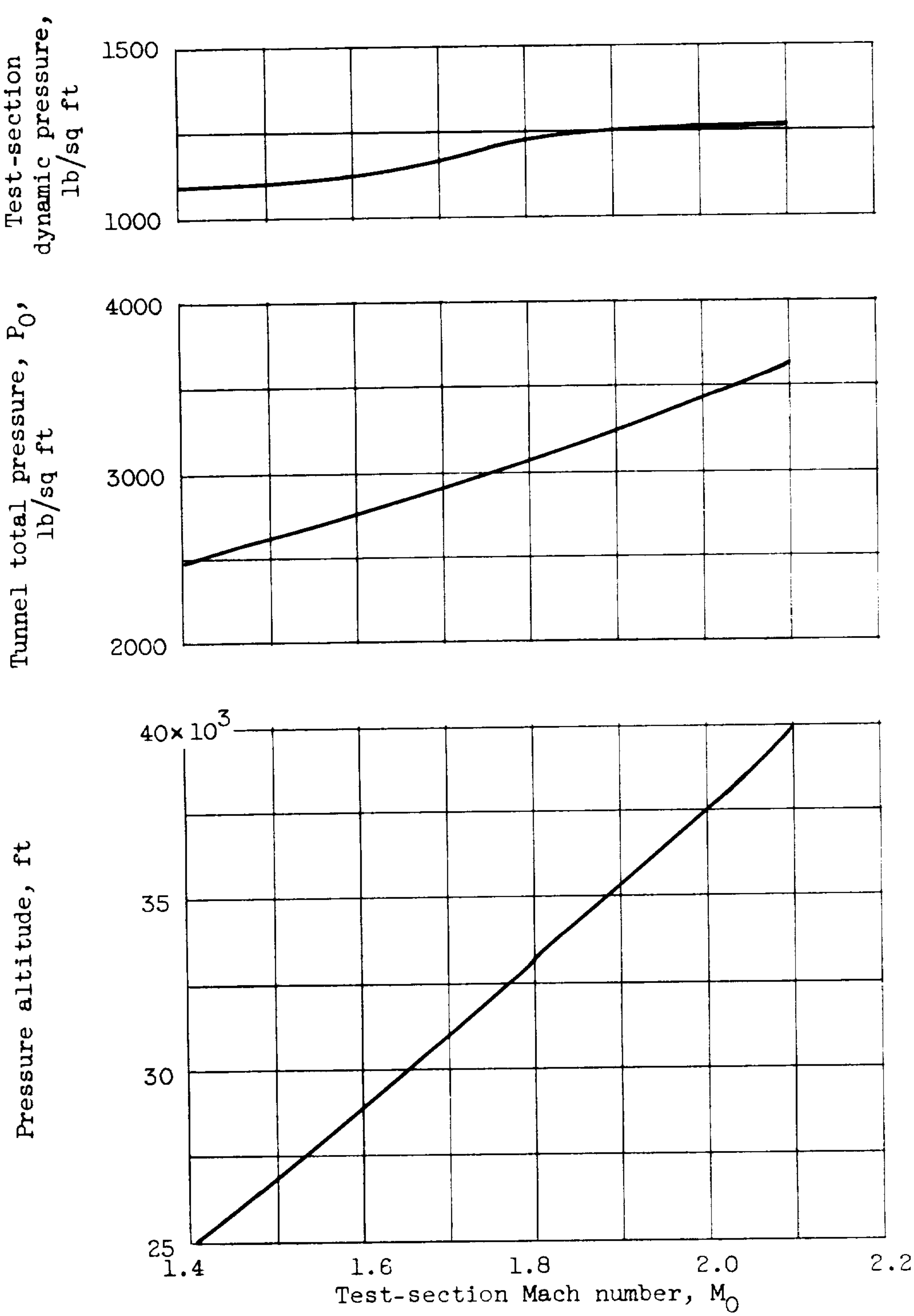
SHIPPING ADDRESS

Materials shipped to the Lewis 8- by 6-foot Supersonic Wind Tunnel to be incorporated as a part of a model or test should be addressed as follows:

8- by 6-foot Supersonic Wind Tunnel
NACA Lewis Flight Propulsion Laboratory
21000 Brookpark Road
Cleveland 11, Ohio

A return address and some type of model identification must be attached to the outside of the box.

[redacted]



Test-section dynamic pressure, lb/sq ft
1500
1000
Tunnel total pressure, P_0, lb/sq ft
4000
3000
2000
Pressure altitude, ft
40×10^3
35
30
25
1.4
1.6
1.8
2.0
2.2
Test-section Mach number, M_0

D. DIAGRAMS: Wiring diagrams of any internal electrical equipment the user furnishes in the model.

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A. ITEMS: The proposed test program should include the following items:

1. List of the data desired: e.g., forces, pressure, mass-flow measurements, pressure distribution, etc.
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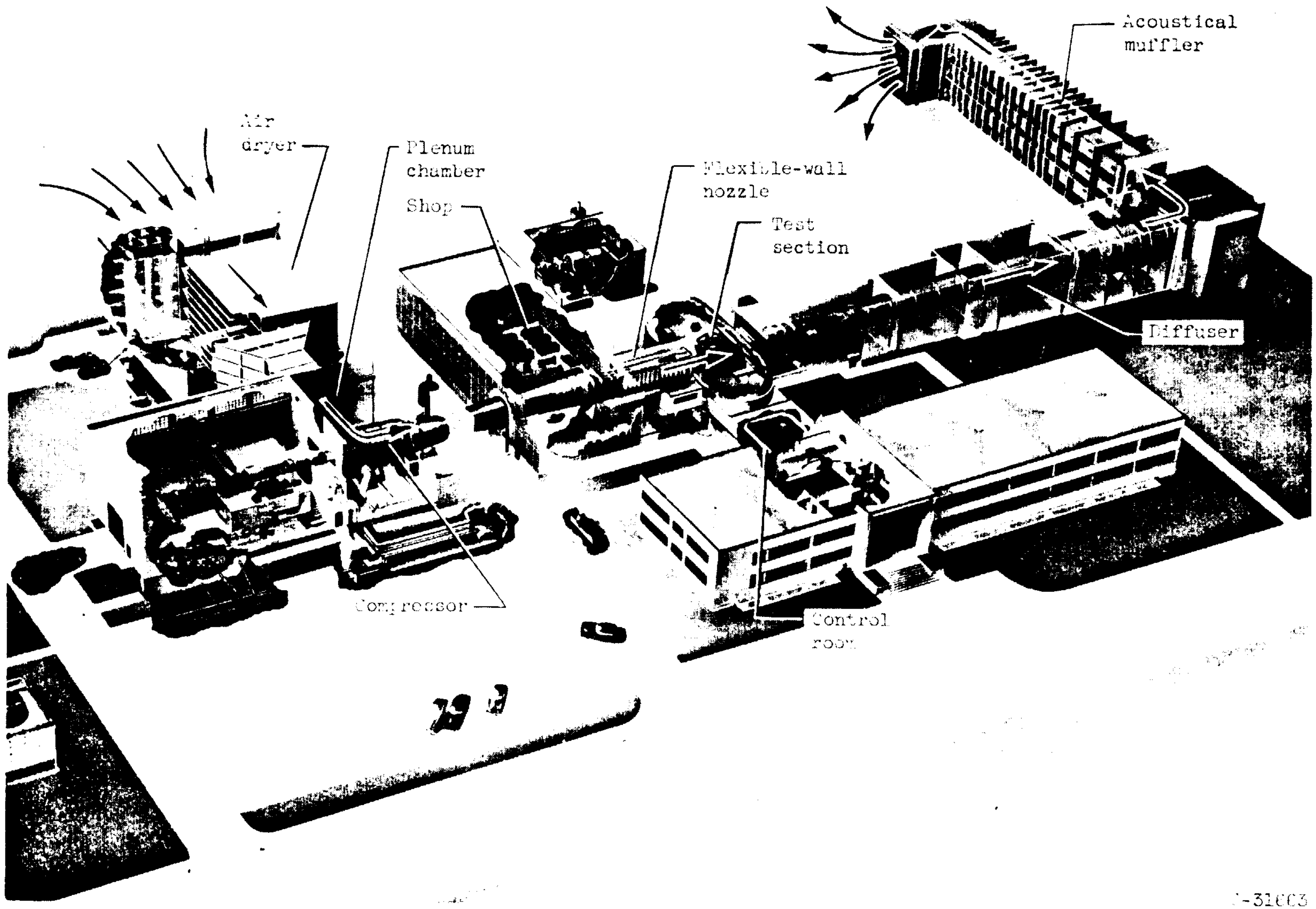

Figure 1. - NACA Lewis 8- by 6-foot Supersonic Wind Tunnel.

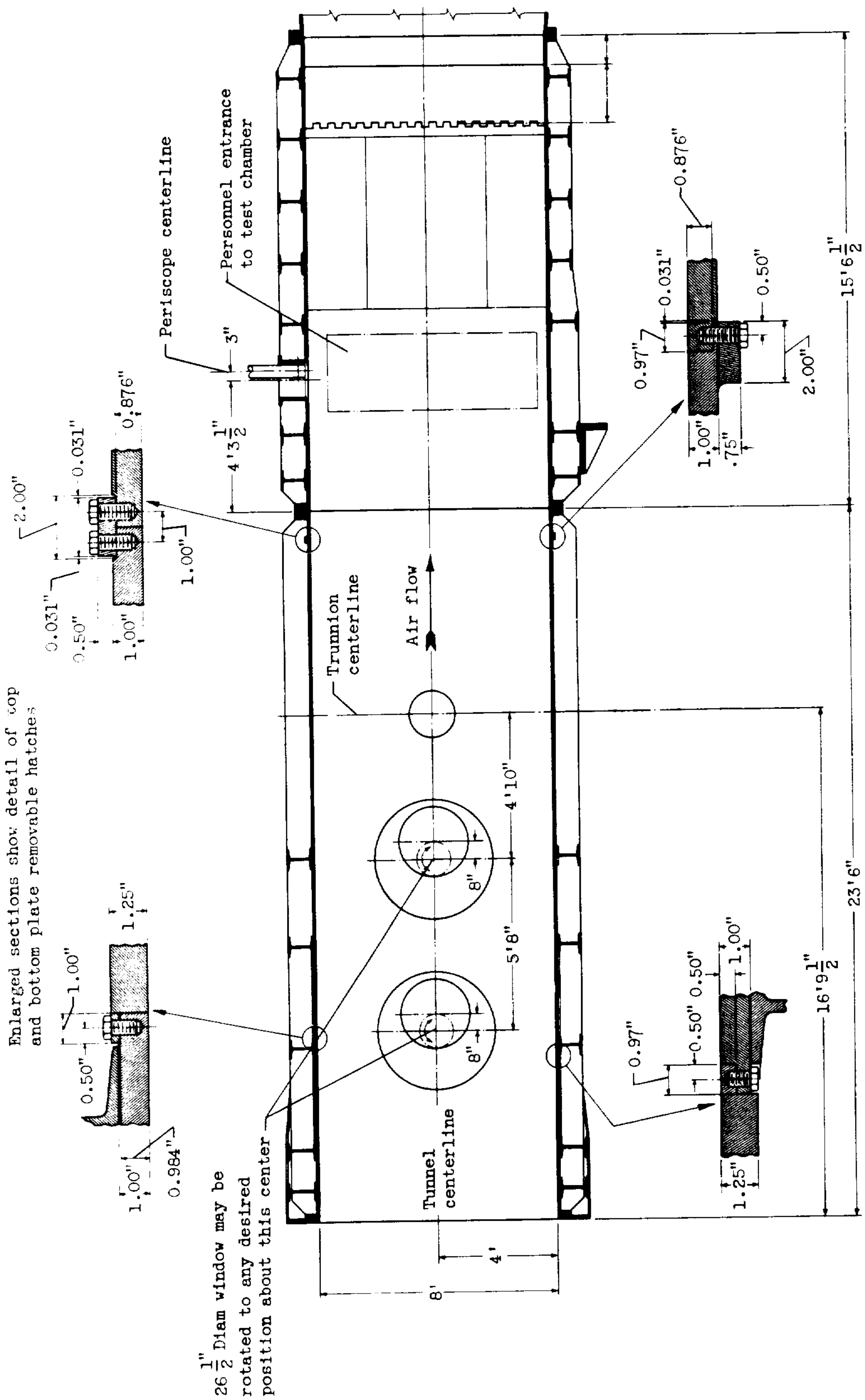

Figure 2. - General arrangement of the 8- by 6-foot test section, Lewis 8- by 6-foot Supersonic Wind Tunnel.

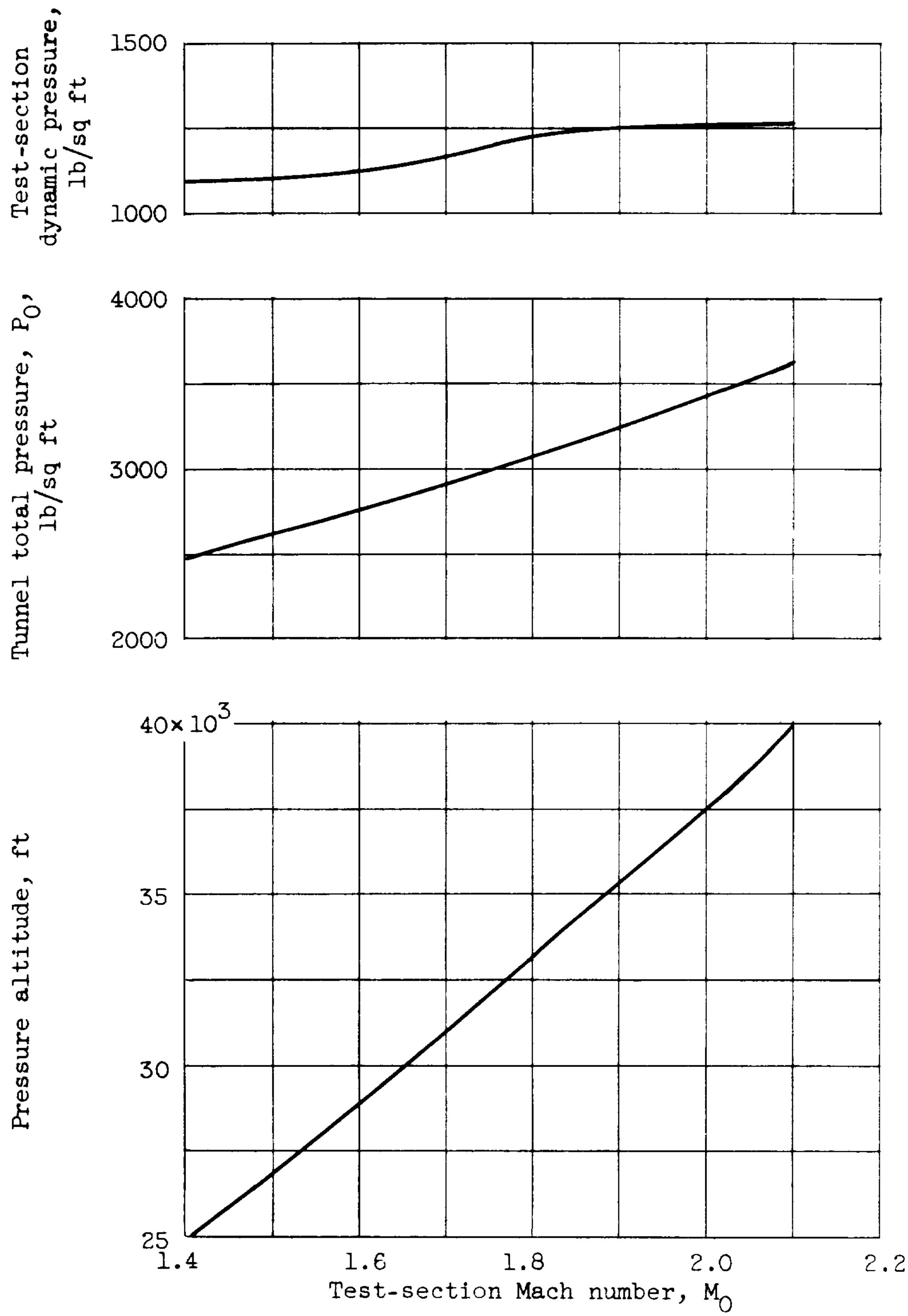

Figure 13. - Performance of 8- by 6-foot tunnel, dynamic and total pressures and pressure altitude, Lewis 8- by 6-foot Supersonic Wind Tunnel.

NACA - Langley Field, Va.

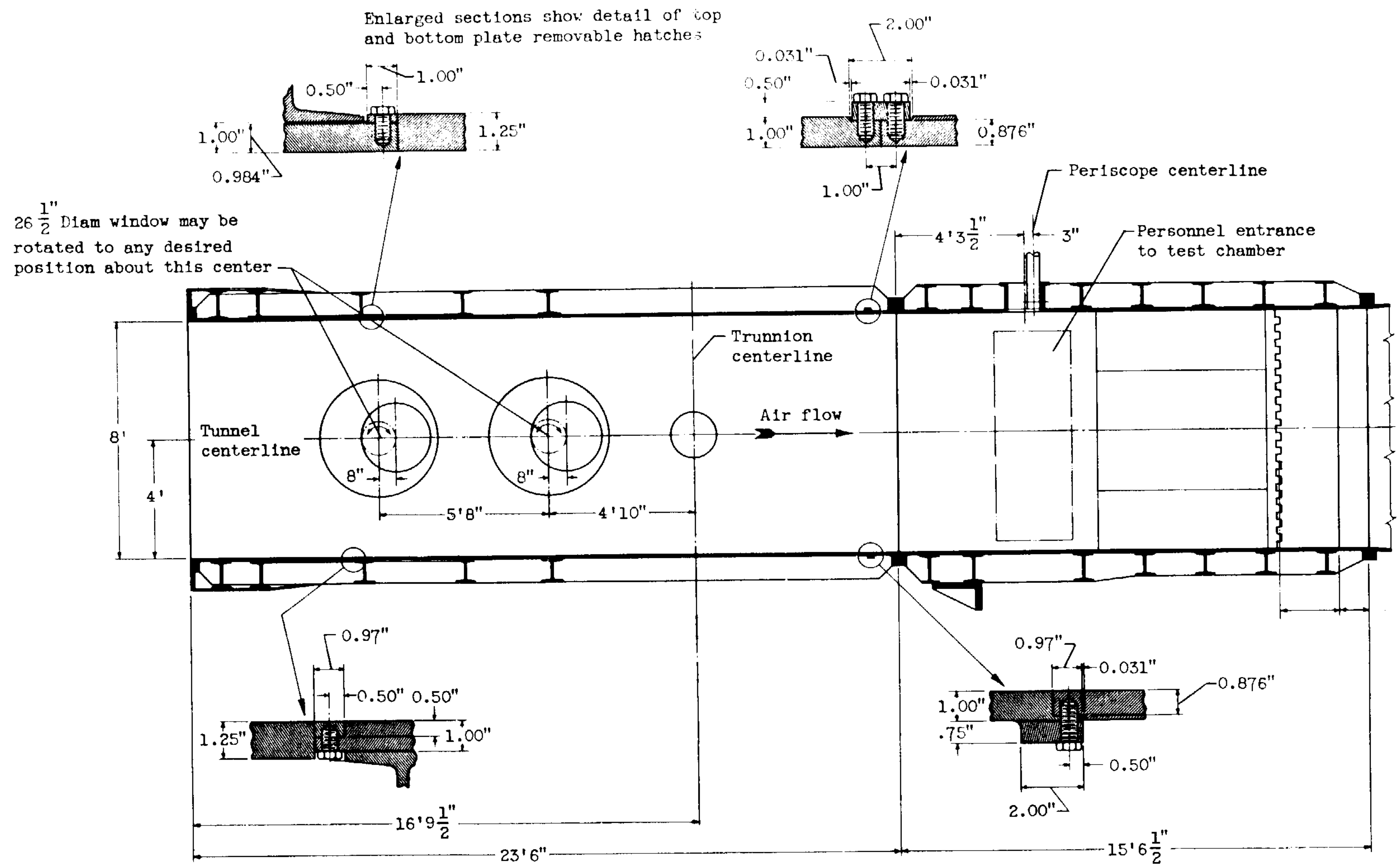

Figure 2. - General arrangement of the 8- by 6-foot test section, Lewis 8- by 6-foot Supersonic Wind Tunnel.

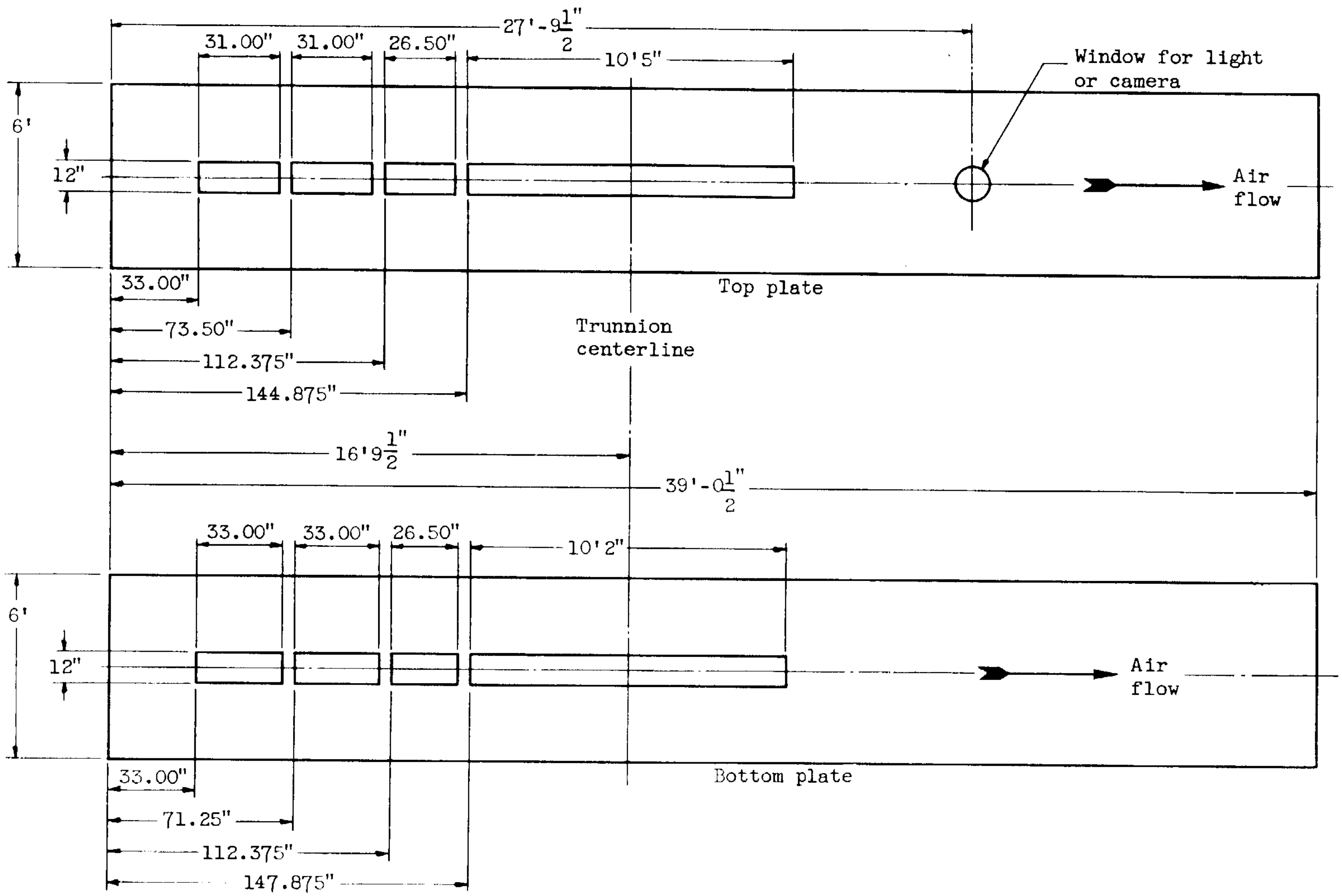

Figure 3. - Top and bottom plate openings, test section, Lewis 8- by 6-foot Supersonic Wind Tunnel.

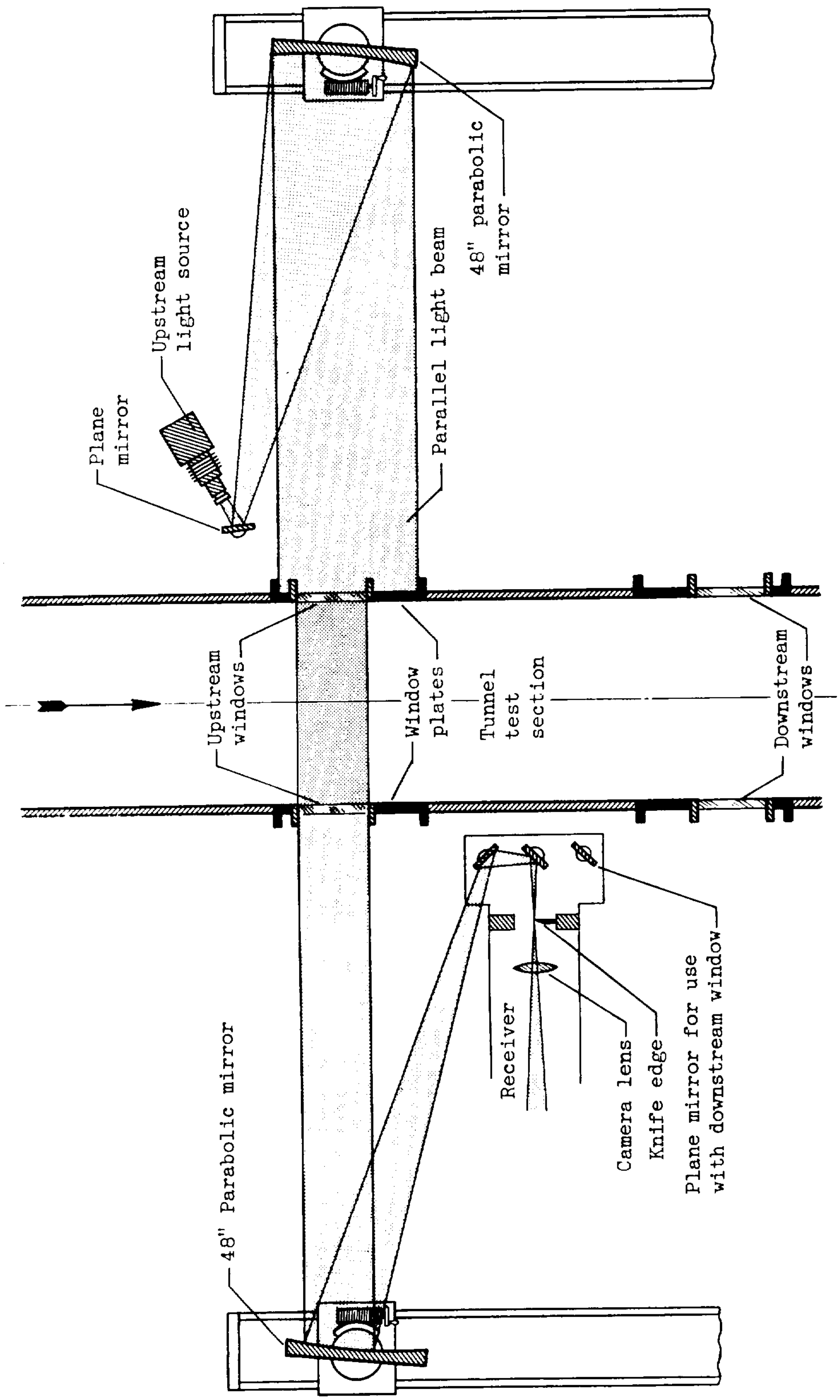

Figure 4. - Plan view of schlieren viewing system, Lewis 8- by 6-foot Supersonic Wind Tunnel.

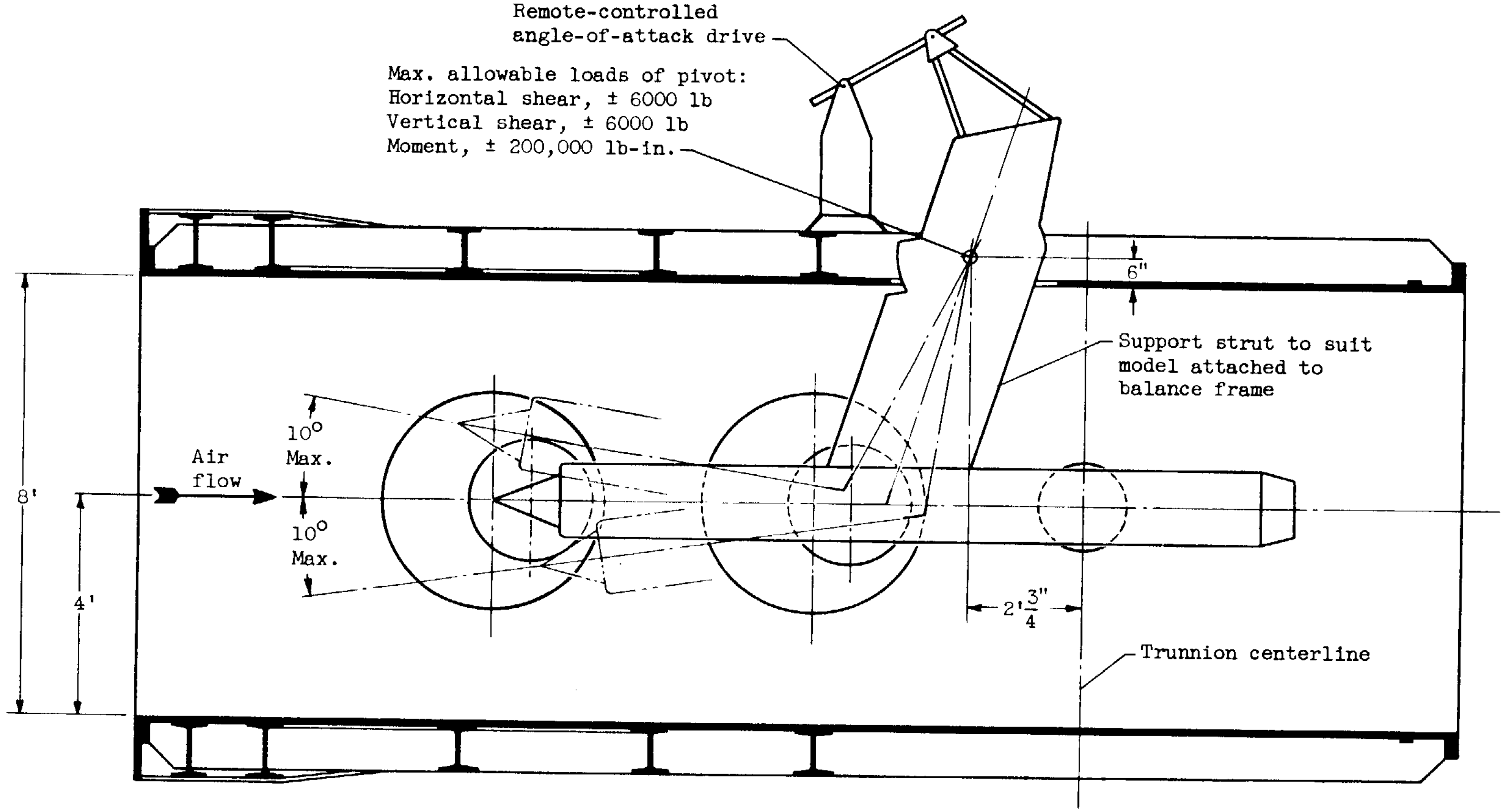

Figure 5. - Models mounted in test section, strut-mounted model, Lewis 8- by 6-foot Supersonic Wind Tunnel.

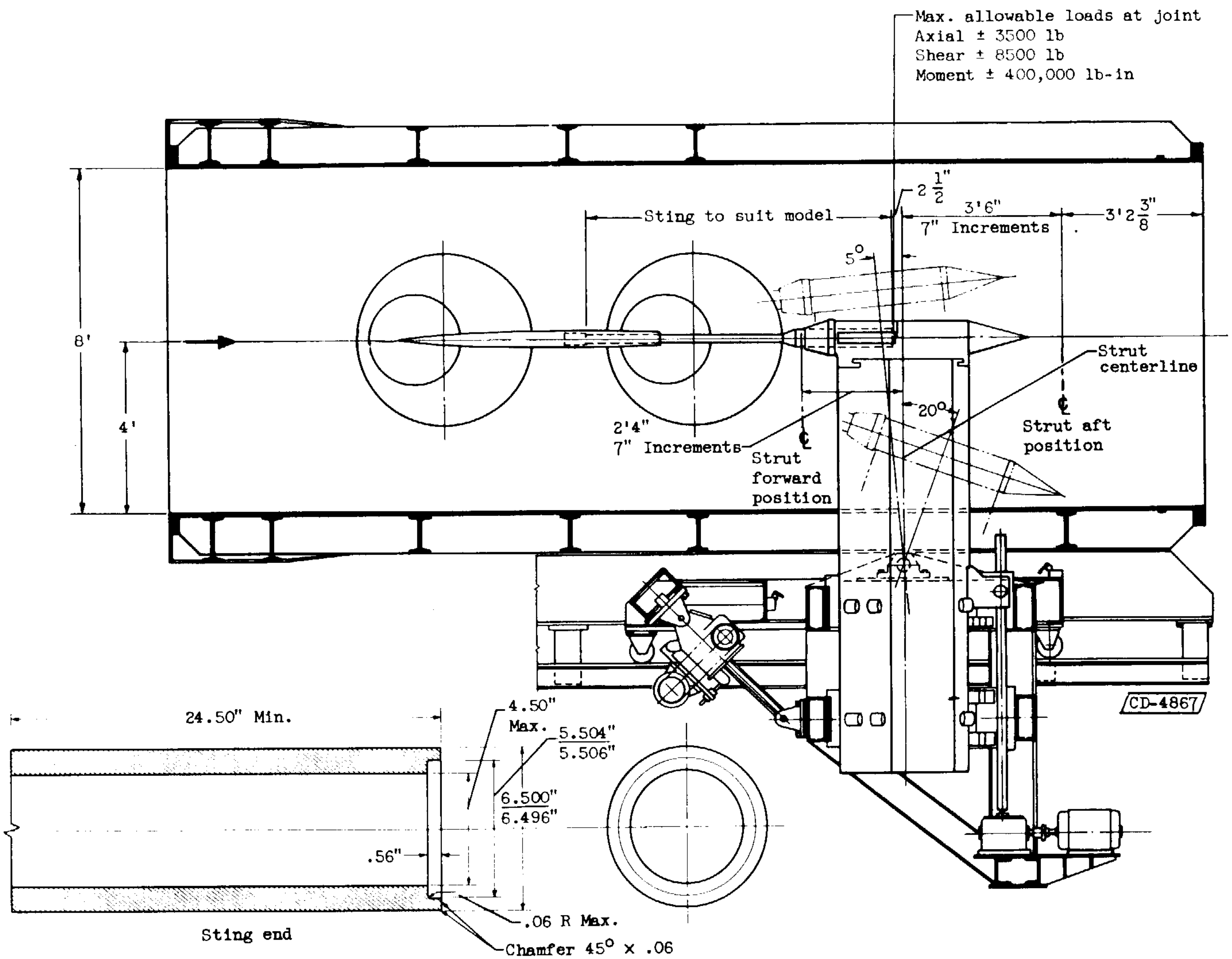

Figure 6. - Model mounted in test section, sting models, Lewis 8- by 6-foot Supersonic Wind Tunnel.

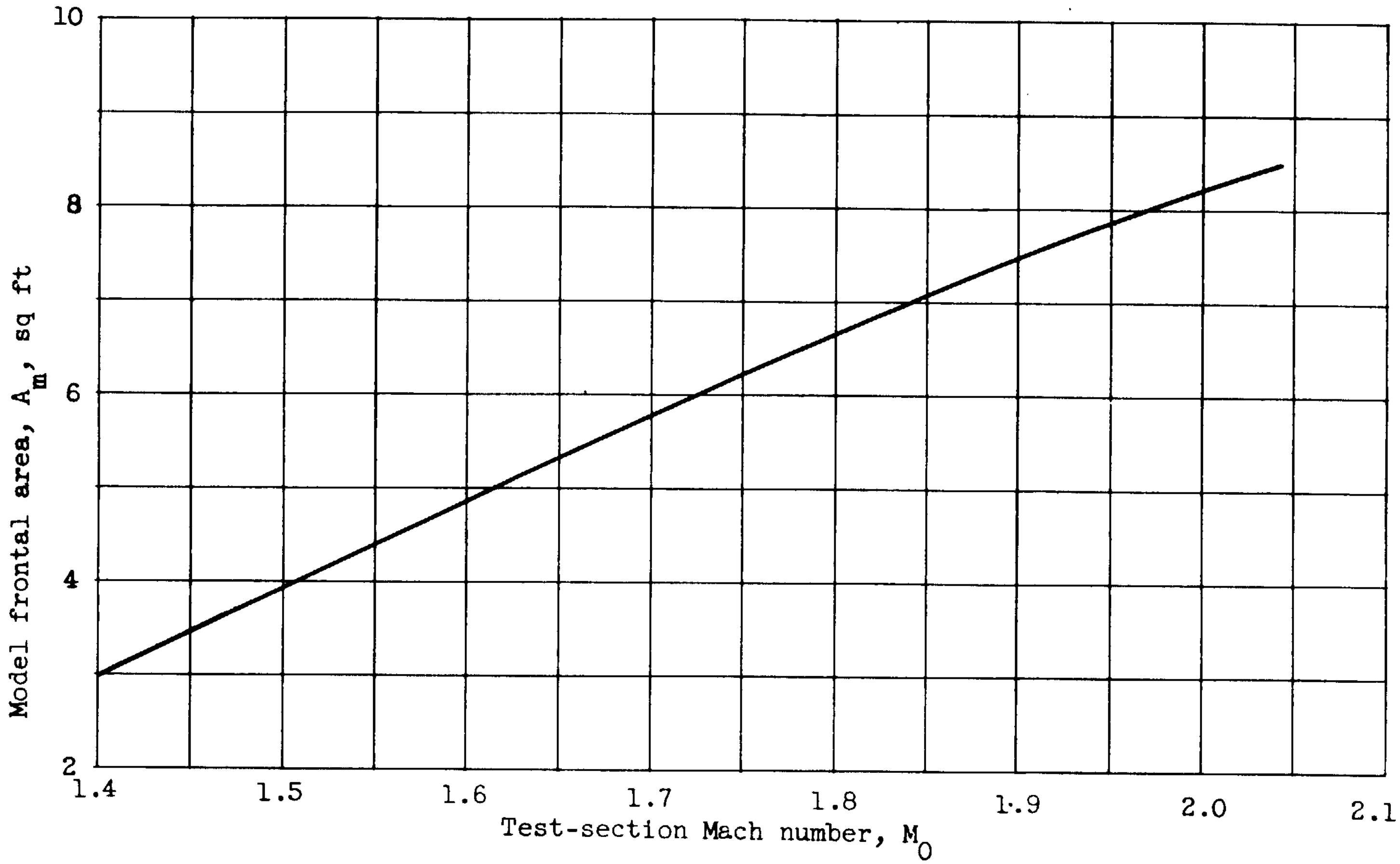

Figure 7. - Maximum model frontal area permitting start of supersonic flow in test section, Lewis 8- by 6-foot Supersonic Wind Tunnel.

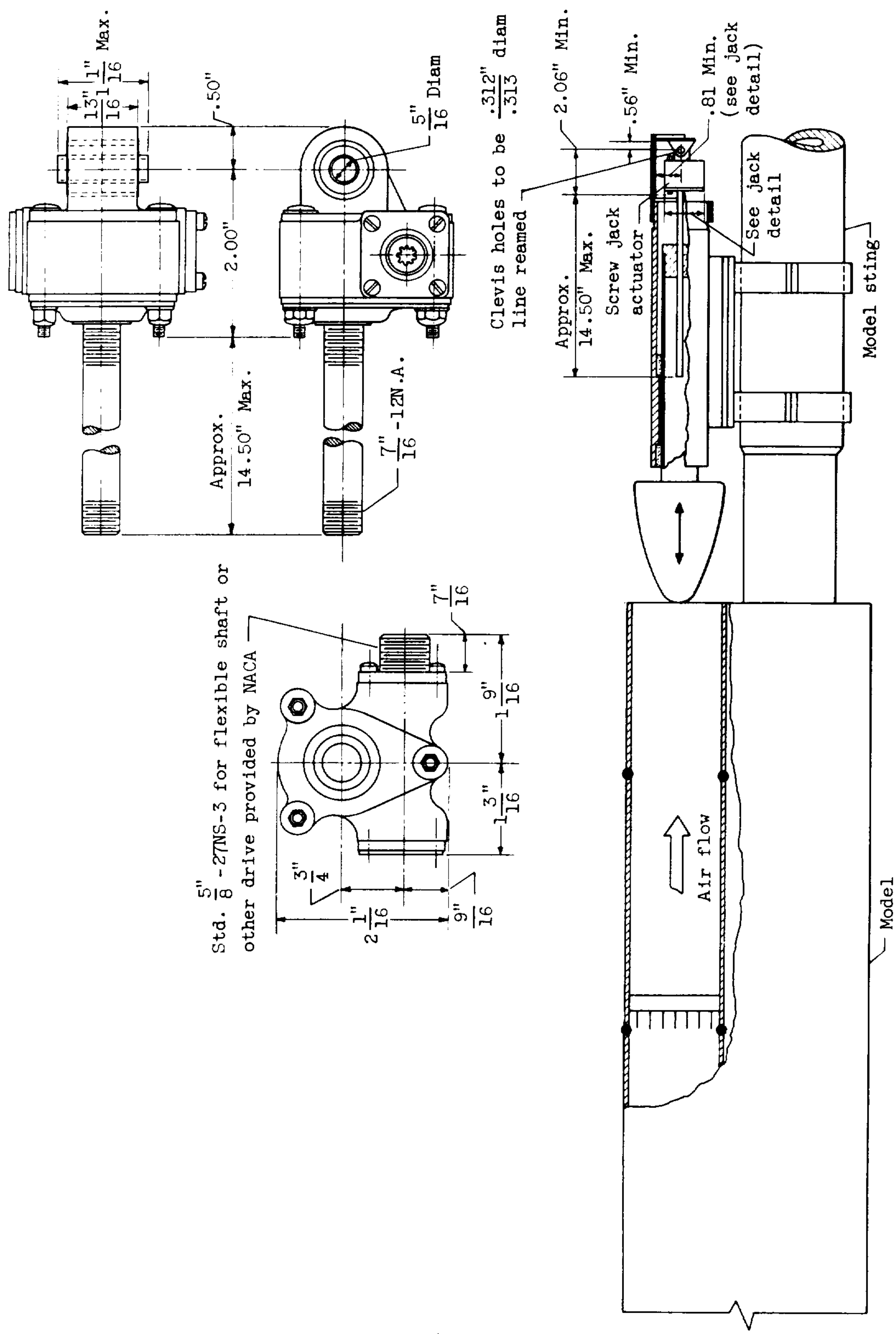

Figure 8. - Schematic plug layout and screwjack actuator, Lewis 8- by 6-foot Supersonic Wind Tunnel.

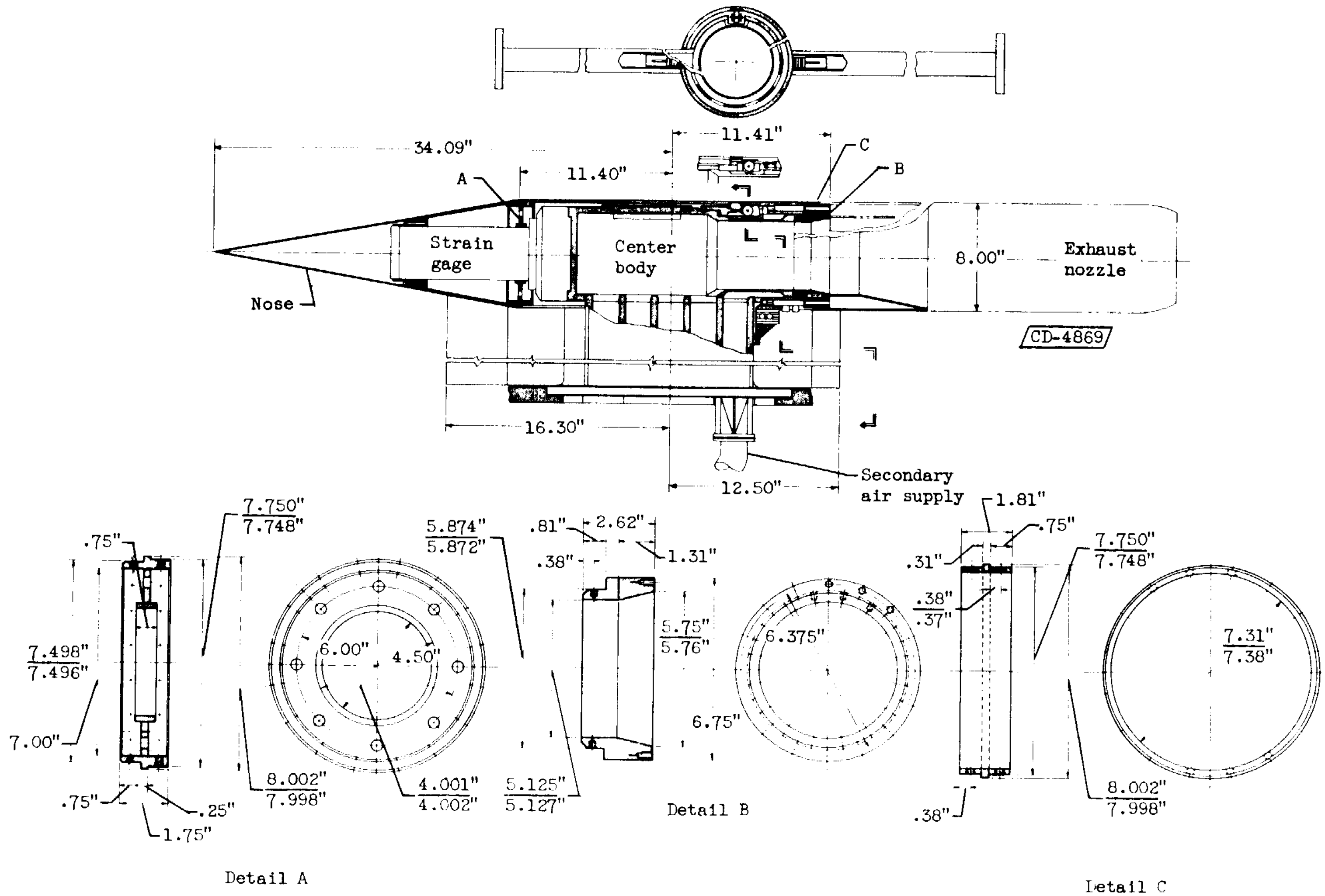

Figure 9. - Jet exit model, Lewis 8- by 6-foot Supersonic Wind Tunnel.

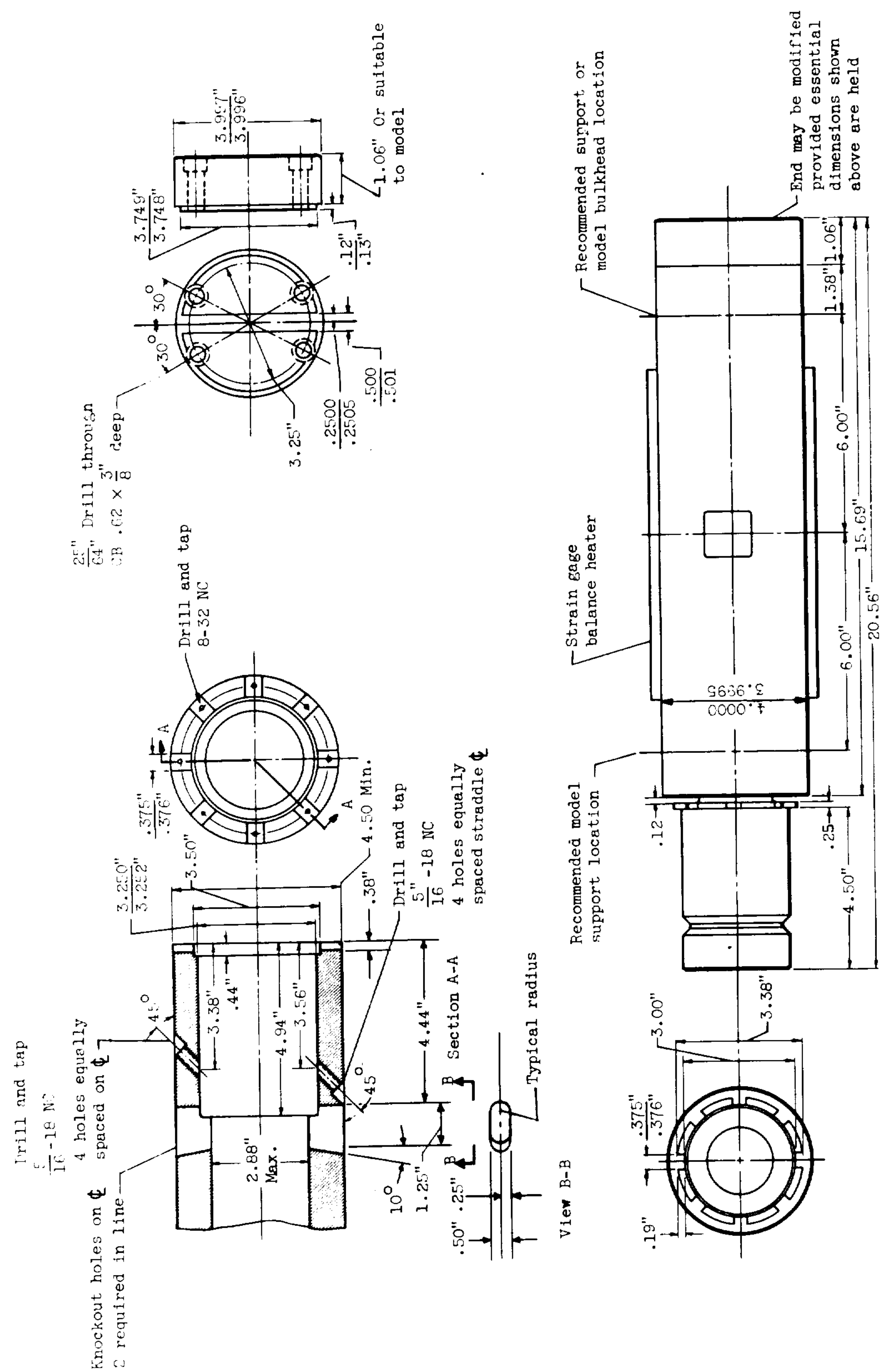

Figure 10.- 4-inch strain-gage balance, Lewis 8- by 6-foot Supersonic Wind Tunnel.

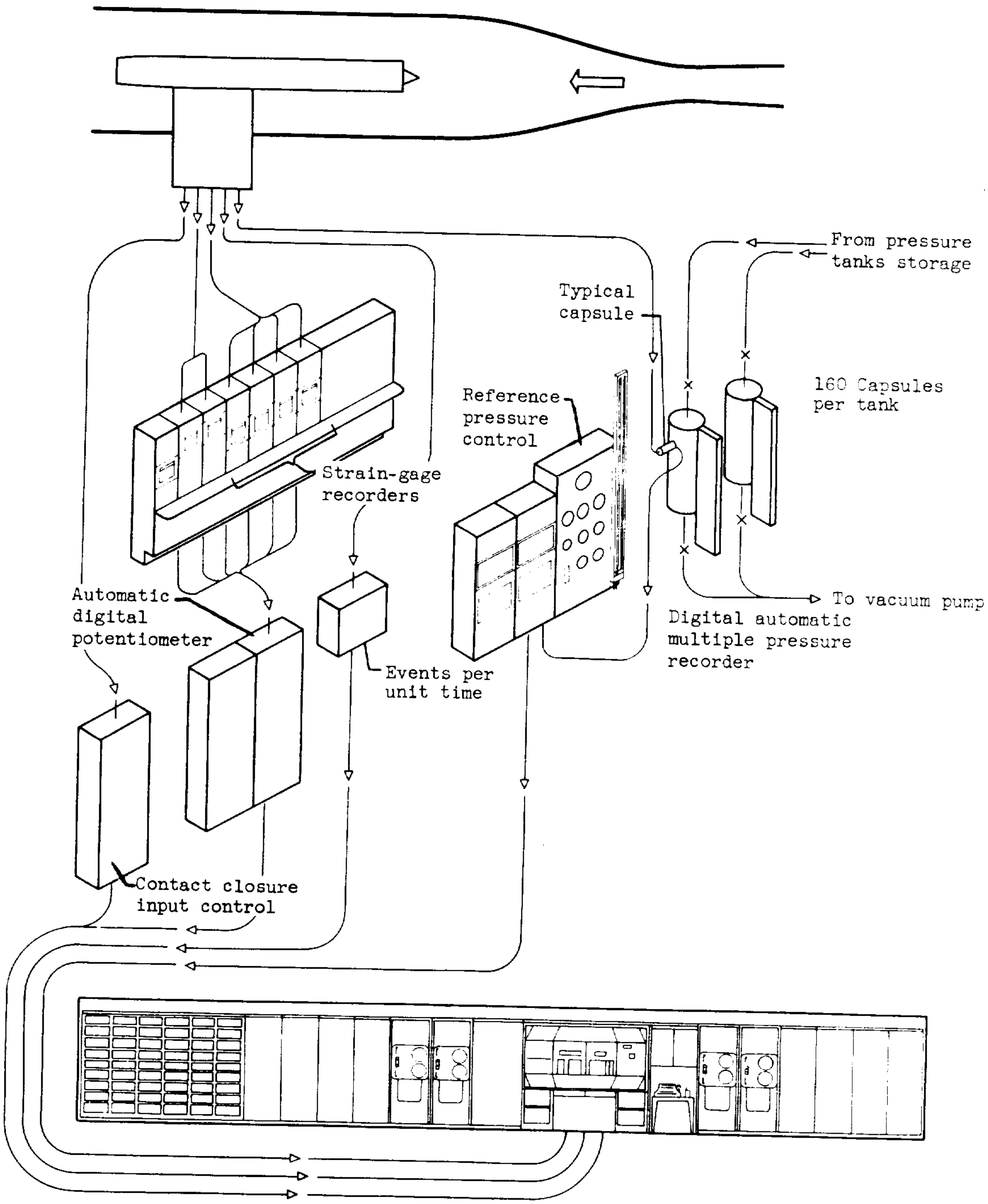

Figure 11. - Wind-tunnel equipment; automatic data recording and processing system, Lewis 8- by 6-foot Supersonic Wind Tunnel.

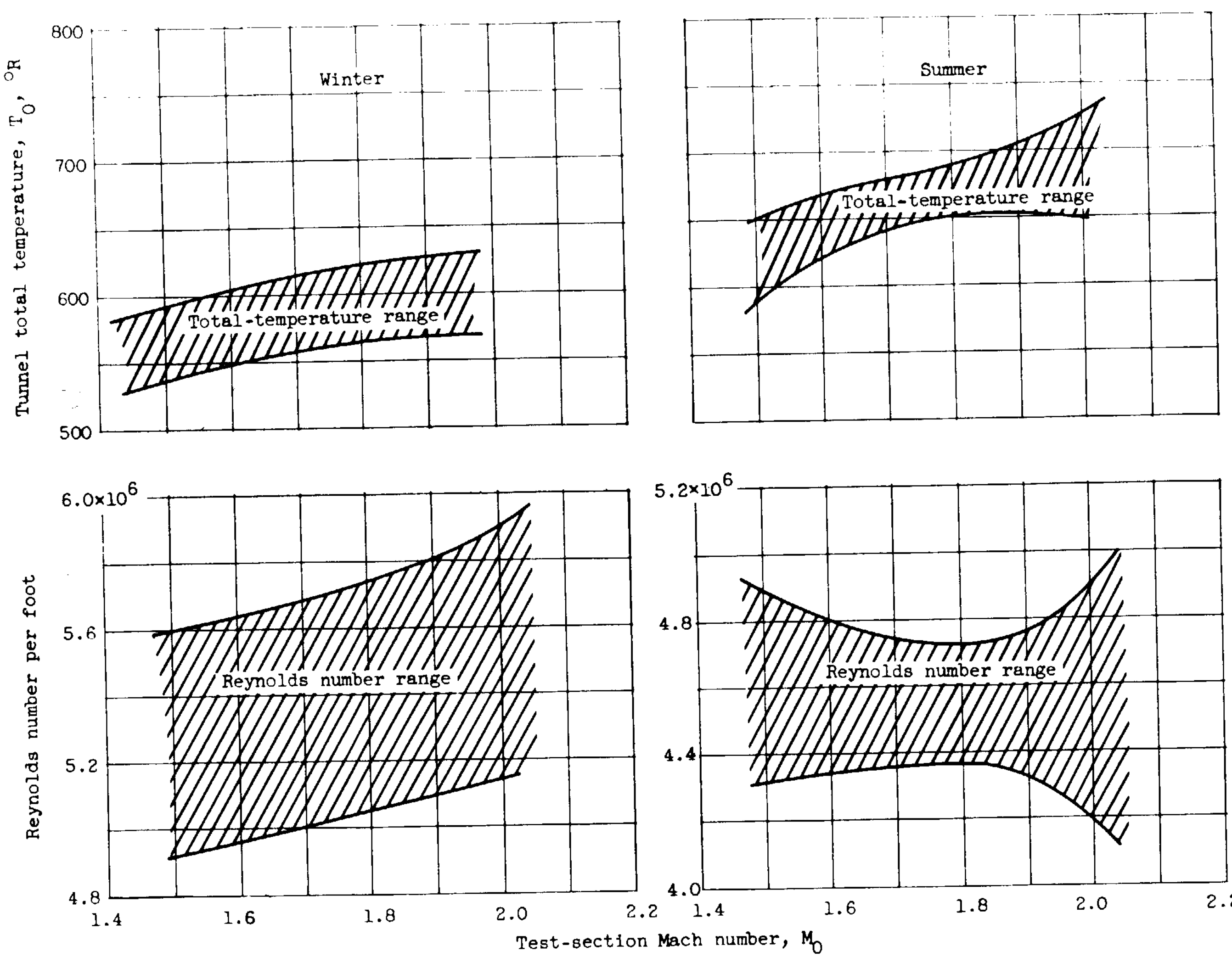

Figure 12. - Performance of 8- by 6-foot tunnel, range of tunnel temperature and Reynolds number in winter and summer, Lewis 8- by 6-foot Supersonic Wind Tunnel.

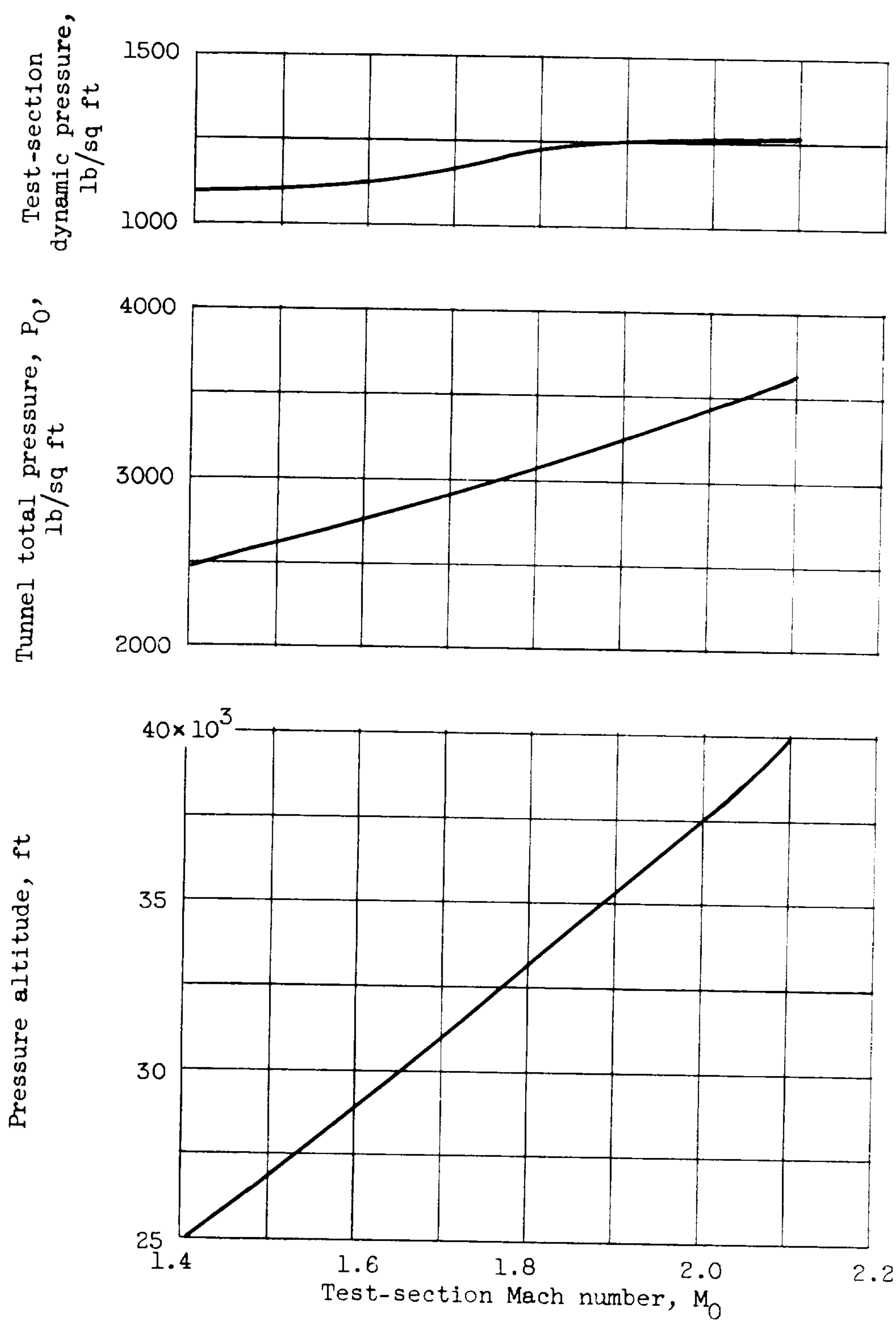

Figure 13. - Performance of 8- by 6-foot tunnel, dynamic and total pressures and pressure altitude, Lewis 8- by 6-foot Supersonic Wind Tunnel.

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